BARANGAROO DEVELOPMENT - THE R8 & R9 BUILDINGS OVER THE SYDNEY METRO CORRIDOR

Report on the measures taken to protect the corridor of the proposed Sydney Metro to allow the construction of the twin railway tunnels with insignificant impacts on the future tunnel design or construction.

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Executive Summary

Mott MacDonald has been engaged by Lend Lease Project Management & Construction (Australia) Pty Ltd to assist in the application of Building R8 & R9 (MP11_0002), where the applicant seeks approval for construction of two residential flat buildings (known as Building R8 & R9) within the vicinity of the future CBD Metro rail corridor.

This report has been prepared to respond to the Director General Requirements for Residential Buildings R8 and R9 (MP11_0002). This report uses the design and construction criteria as accepted by NSW Transport proposed for the buildings over the future Sydney Metro as presented in our report entitled "Barangaroo Development – Protection of the Sydney Metro Corridor" dated 22nd February 2011 which concentrated on objectively reviewing the requirements of the "Development Guidelines within the vicinity of the Sydney Metro Network Line 1" of March 2010, Rev. A-1 in the context of development proposed by Lend Lease at Barangaroo South as described under the Basement and Bulk Earthworks Project Application MP 10 0023 and subsequent proposed amendments under 75W application and a proposed future Building C5 (MP10_0027) Project Application contemplated by DGR's MP10_0027.

The response to Director General Requirements for R8 & R9 Buildings (MP11_0002) has identified only operational noise and vibration issues associated with the future CBD Metro. It is recommended that these issues be addressed by the building designers in the design of the Lend Lease basement for R8 & R9 Buildings on the basis that the track in the tunnel itself will be laid on a floating track slab beneath the R8 & R9 Buildings.

With reference to the Lend Lease prepared Structural Foundation Preliminary Design and the agreed (with the Department of Transport) structural design and construction criteria, the encroachments arising out of the Bulk Excavation and Basement Car Parking MP10_0023 and foundations of the Buildings R8 & R9 (MP11_0002), that the commensurate structural loads, and the resulting geotechnical conditions, it has been demonstrated that ***"…encroachment will not have unacceptable structural or operational impacts on the metro corridor"*** and hence ***"will not impede the metro rail corridor or affect the future operations of the metro project…"*** as required by the relevant Director General's Requirement.

The proposed key elements of the structural design and construct criteria are:

- The establishment and adoption of an integrated survey grid between the Lend Lease development at Barangaroo South and the CBD Metro including the subsequent verification of Works as Executed drawings.

- The establishment of a 1 metre minimum clearance between the CBD Metro tunnels and walls, columns or foundation elements associated with Bulk Excavation and Basement Car Parking MP10_0023, and Building R9 (MP11_0002). This is in addition to appropriate construction tolerances. The minimum clearance does not apply to Building R8, as the foundation footprint is located approximately 80m distance away from the future Sydney Metro.

- Where required, the founding of all vertical structures associated with the Building R9 (MP11_0002) at a level below the zone of influence of the CBD Metro tunnels (or as agreed). The preliminary design shows the piles with their rock sockets founded below the tunnel invert. The piles sleeving length is to be determined by Geotechnical Consultant based on Sydney Metro Zone of Influence. However, if we assume that the piles are not isolated from the rock above the tunnel invert. Firstly, the steel reinforced bored concrete piles are stiffer than the surrounding rock which will facilitate the direct transfer of load through pile rather than into the rock. Secondly, if the rock is disturbed adjacent to the pile above the tunnel invert during tunneling by the Tunnel Boring Machine (TBM) this principle of load transference to the rock socket below still applies and will only be enhanced.

- Upon the completion of the Barangaroo South development, all the ground above the crown of the future metro tunnels under the slab spanning between the piles supporting Building R9 (MP11_0002) is retained. The minimum clearance from the underside of the slab to the crown of the future Sydney Metro tunnels will be greater than 2m.

- The concrete segments are erected within the tail of the TBM shield. Pea gravel (followed later by high pressure grouting) or high pressure grouting alone from the within the tail shield of the TBM will fill the annulus formed between the surrounding ground the segmental lining. Grouting of the segments within or behind the tail shield of the TBM is an industry standard method of tunnel construction when using segments. Additional grouting of the ground can be preformed through cast in holes in the segments if required to fill potential voids formed above the tunnel.

- Transport NSW should ensure that when the tunnel is excavated under the building an additional level of tunnel construction surveillance is applied to that used outside the building foot print.

- The TBM can traverse beneath the load transfer slab above without the need for surface grouting during the tunneling works and therefore no penetrations in the slab or structural elements adjacent to the tunnel are required. In the case of a 1.8m thick slab and depending on the building use in the basement above this may be impractical to achieve anyway. Grouting of the ground surrounding the tunnel is in this case more efficiently carried out from within the tunnel. The integrity of the ground around the tunnel is required to be maintained to reduce lining deformation and tunnel lining flotation.

In addition to the above design and construct criteria, it will important to ensure that the detailed designs and construction methodology are closely coordinated in an ongoing manner. Mott MacDonald therefore recommends that appropriate approvals regimes are established between Lend Lease and Sydney Metro.

The preliminary design of the building is consistent with the design and construction principles agreed with NSW Transport and therefore detailed design of the building should be allowed to proceed on the basis of the conclusions, procedures and preliminary foundation structural drawings presented in this report.

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1.0 Introduction

1.1 Purpose of Report

This report supports a Project Application (MP11_0002) submitted to the Minister for Planning pursuant to Part 3A of the Environmental Planning and Assessment Act 1979 (EP&A Act). The Application seeks approval for construction of two residential flat buildings (known as Buildings R8 and R9) and associated works at Barangaroo South as described in the Overview of Proposed Development section of this report.

This report addresses the Director General Requirements (DGR) for Building R8 & R9 Residential Buildings includes the following in relation to the Sydney Metro:

DGR No.5 Land Use (in part): Demonstrate that the proposed development will not impede the metro rail corridor or affect the future operations of the metro project.

1.2 Overview of Proposed Development

The R8 and R9 Project Application seeks approval for the construction and use of two residential flat buildings comprising 161 apartments, ground floor retail, allocation of car parking spaces from the Bulk Excavation and Basement Car Parking Project Application, and the construction of the surrounding ancillary temporary public domain and landscaping.

1.3 Background

1.3.1 CBD Metro

The CBD Metro, originally announced by the NSW Government on 23 October 2008, is a proposed metro line running in Sydney that was designed to cater to the "CBD Growth Centre". It was identified as the enabling "central spine" to a proposed larger metro system for Sydney, including extensions to the west and possibly the north-west.

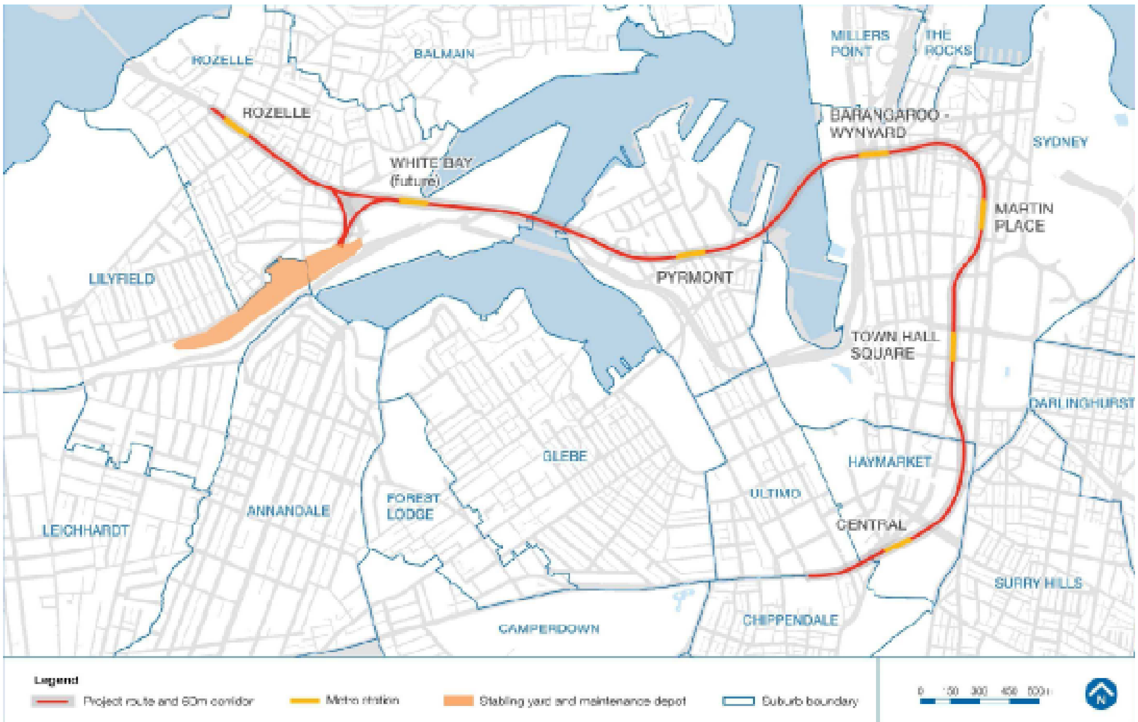


Figure 1: CBD Metro Proposed Route (Line 1)

The design for the CBD Metro comprises a 7-kilometre underground railway within twin tunnels, each about six metres internal diameter, running from Rozelle and Pyrmont to connect with Barangaroo-Wynyard, Town Hall and Central as shown in Figure 1. The metro was proposed to offer a rail service of one train every two to three minutes in the peak with a daytime maximum waiting time of five minutes in the off peak. It was to run single deck rolling stock along the route of the proposed CBD Metro.

Planning approval for this major project was achieved on 1 January 2010 via Part 3A of the Environmental Planning and Assessment Act 1979.

1.3.2 Metro Station Relocation Scheme

On the 21st of February 2010, the NSW Government announced that all work on the Stage 1 CBD Metro was to be stopped with all resources and funding to be reallocated to other projects and transport plans over the next 10 years.

This meant that the CBD Metro, including the proposed Barangaroo-Wynyard Station, would not be built prior to the development of Barangaroo. The area that was to be used as the construction site for the Station will no longer be available if the CBD Metro project is re-established. In addition, a large portion of the Station was to be constructed via 'cut and cover' construction techniques which will no longer be possible.

As a result of this announcement, Lend Lease began consultation with both Sydney Metro (now Department of Transport) and the BDA in May 2010 regarding development and construction delivery options for the portion of the Barangaroo/Wynyard station within Barangaroo. On 9 July 2010 Department of Transport indicated to both the Barangaroo Delivery Authority and Lend Lease that they were open to the investigation of the feasibility of relocating the station off the Barangaroo site. As a result of this, Lend Lease engaged HASSELL to develop various study options for the relocation of the station. HASSELL were chosen due to their prior involvement with the 'PBACH' consortium in the design of the original CBD Metro stations.

A preferred scheme was identified and designed to a developed concept level. A report was prepared by HASSELL and Lend Lease entitled "Barangaroo-Wynyard Station Relocation Scheme" and dated 14 December 2010. The acceptance of this report by the Department of Transport enables development and construction works to be undertaken within the area previously reserved for the CBD Metro station box.

1.3.3 The Barangaroo Site

The 22 hectare Barangaroo site has been divided into three distinct redevelopment areas (from north to south) – the Headland Park, Barangaroo Stage 2 and Barangaroo Stage 1 (herein after referred to as Barangaroo South). Lend Lease was successfully appointed as the preferred proponent to develop Barangaroo Stage 1 (otherwise known as Barangaroo South) on 20 December 2009.

1.3.3 Site History

The selected historical Maps of Sydney presented within Appendix A indicate that much of the Barangaroo site is reclaimed land between historical shipping wharves and berths. The wharves structures were assessed by Sinclair Knight Merz (SKM) in August 2005 and typically comprise reinforced concrete caisson construction filled with sand material. One Wharf comprised steel piles topped with a suspended slab.

1.3.4 Planning History and Framework

On 9 February 2007 the Minister for Planning approved a Concept Plan for the site and on 12 October 2007 the land was rezoned to facilitate its redevelopment. The Approved Concept Plan allowed for a mixed use development involving a maximum of 388,300m^2 of gross floor area (GFA) contained within 8 blocks on a total site area of 22 hectares.

Modification No. 1 was approved in September 2007 which corrected a number of minor typographical errors.

On 25 February 2009 the Minister approved Modification No. 2 to the Concept Plan. The Approved Concept Plan as modified allowed for a mixed use development involving a maximum of 508,300m^2 of gross floor area (GFA) contained within 8 blocks on a total site area of 22 hectares.

On 11 November 2009 the Minister approved Modification No. 3 to the Concept Plan to allow for a modified design for the Headland Park and Northern Cove. The Approved Concept Plan as modified allows for a mixed use development involving a maximum of 489,500m^2 of gross floor area (GFA) across Barangaroo as a whole.

On 16 December 2010 the Minister approved Modification No. 4 to the Barangaroo Concept Plan. The Approved Concept Plan as modified allows for approximately 563,965sqm Gross Floor Area of mixed use development across the entire Barangaroo site.

This Project Application forms one of a series of individual Project Applications that Lend Lease will be submitting to deliver Barangaroo South. This Project Application is consistent with the established planning framework for the site, including the approved Concept Plan (as modified).

On 2 November 2010 the Minister approved the Bulk Excavation and Basement Car Parking Project Application (MP10_0023) to accommodate up to 880 car parking spaces and associated services and infrastructure to support the initial phases of the future development of Barangaroo South.

On 3 March 2011 the Minister approved Modification No.1 to the Bulk Excavation and Basement Car Parking MP10_0023. This approval extended the area of the approved basement to the south. The area of the proposed extension is directly beneath the site of the proposed Building R8 & R9. The proposed modified works will include additional excavation and bulk earthworks and on-site treatment and remediation of additional contaminated soils and an extension to the basement structure to accommodate.

On 18 April 2012 the Minister approved the Building C5 (MP10_0027) Project Application (MP10_0027) for the construction of commercial building C5, allocation of car parking spaces, temporary public domain works, remediation and associated works. The approval was granted for piling and associated earthworks and remediation.

1.3.5 Site Location

Barangaroo is located on the north western edge of the Sydney Central Business District, bounded by Sydney Harbour to the west and north, the historic precinct of Millers Point (for the northern half), The Rocks and the Sydney Harbour Bridge approach to the east; and bounded to the south by a range of new development dominated by large CBD commercial tenants.

The Barangaroo site has been divided into three distinct redevelopment areas (from north to south) – the Headland Park, Barangaroo Central and Barangaroo South.

The R8 and R9 Project Application Site area is located within Barangaroo South as shown in Figure 1. The Project Application Site extends over land generally known and identified in the approved Concept Plan as Block X.

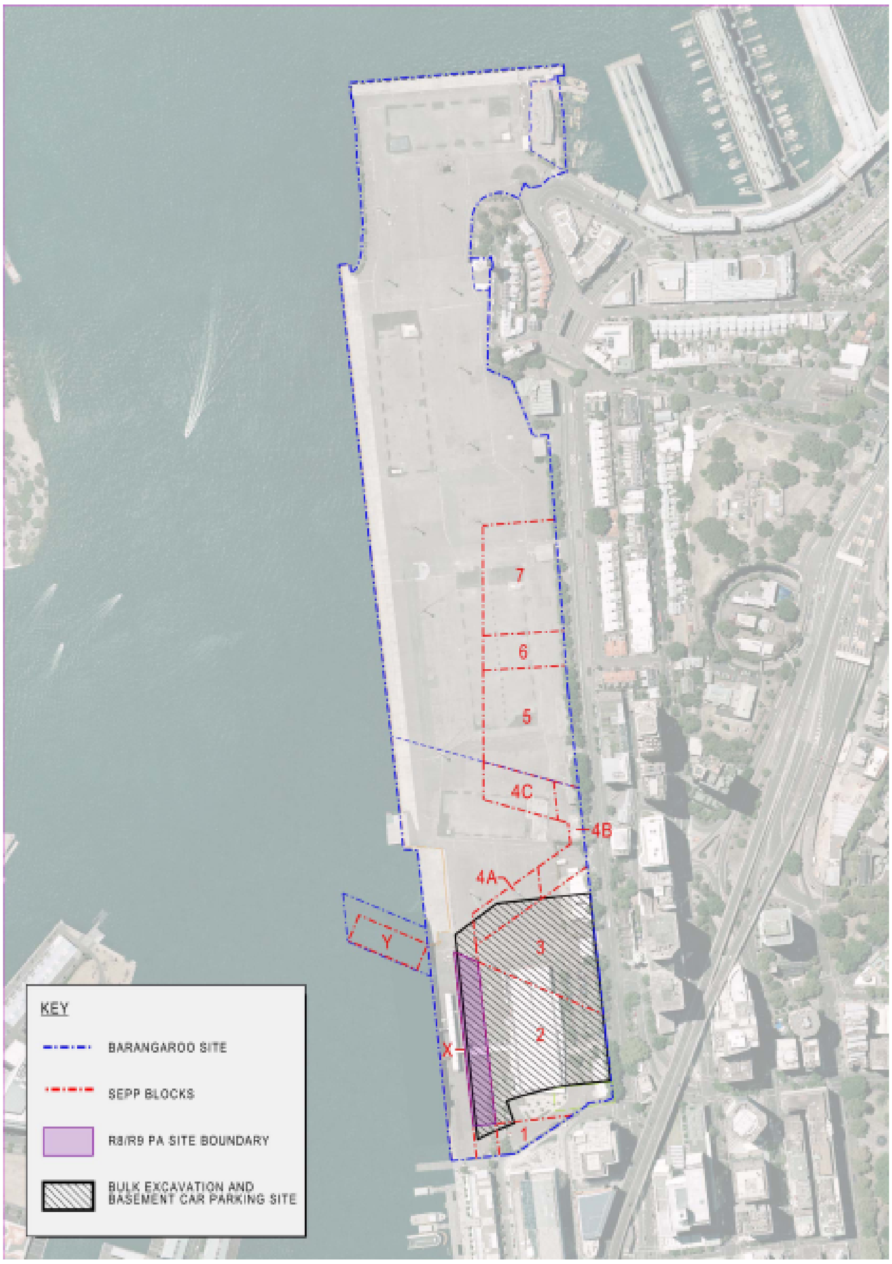


Figure 1: R8 & R9 Residential Building Project Application (MP11_0002) Aerial Site Location Plan

This Project Application seeks approval for the construction of R8 & R9 Residential Buildings, comprising ground floor retail, 9 and 7 levels of residential apartments respectively provision for associated cars and bicycle parking and the construction of the surrounding ancillary public domain which includes access streets and landscaping.

1.3 Previous Consultation and Reports

Extensive consultation was undertaken between the Department of Transport, the Barangaroo Delivery Authority, Lend Lease and relevant specialist consultants as part of the first modification to the Bulk Excavation and Basement Car Parking planning approval (which was approved on 3 March

2011). A report was produced by Mott MacDonald entitled "Barangaroo Development – Protection of the Sydney Metro Corridor" dated 22 February 2011 (***Basement Report***).

The ***Basement Report*** was structured in two parts:

- **Part A** is a supplementary report to assess and demonstrate compliance in relation to the Bulk Excavation and Basement Car Parking under the section 75W application in relation to the interaction with the Sydney Metro Line. It addresses the relevant requirements of the 'Development Guidelines within the Vicinity of the Sydney Metro Network Line 1 Sydney Metro Authority – 30/0302010 (Guidelines); and

- **Part B** assessed and established principles for the future design and construction of Building C5 which is proposed to be developed in the vicinity of the CBD Metro corridor, of which a scheme of sufficient detail for Project Application purposes was still to be developed.

Risk tables were prepared to cover both Part A and Part B of the Basement Report.

The ***Basement Report*** concluded the following key elements of the structural design and construct criteria:

- The establishment and adoption of an integrated survey grid between the Lend Lease development at Barangaroo South and the CBD Metro including the subsequent verification of Works as Executed drawings.

- The establishment of a 1 meter minimum clearance between the CBD Metro tunnels and walls, columns or foundation elements associated with Bulk Excavation and Basement Car Parking MP10_0023 and Building C5 MP10_0227. This is in addition to appropriate construction tolerances.

- Where required, the founding of all vertical structures associated with the Bulk Excavation and Basement Car Parking MP10_0023 and Building C5 MP10_0227 at a level below the zone of influence of the CBD Metro tunnels (or as agreed).

  Upon the completion of the Barangaroo South development, all the ground above the crown of the future metro tunnels under the slab spanning between the piles supporting Building C5 is retained. The minimum clearance from the underside of the slab to the crown of the future Sydney Metro tunnels will be greater than 2m.

A graphical representation of these key structural parameters is provided in the Generic Structural Foundation Concepts included at Appendix C of this report. These Concepts were also included in the ***Basement Report***.

This R8 & R9 Residential Building Report over the Sydney Metro Corridor reiterates and uses the agreed criteria to progress the building design using the agreed minimum distances between the Barangaroo basement, and R8 & R9 Residential structures and the future CBD Metro corridor tunnels and demonstrates, using a risk assessment approach similar to that used for the ***Basement Report and C5 Building Report***, why there is negligible risk that the proposed development will have an adverse effect on the Metro either in the construction phase or during operation.

2.0 Mott MacDonald - Background

Mott MacDonald are an international engineering consultant with 120 permanent offices around the world. We have 14,500 staff worldwide and recently entered the Australian market under our own name as Mott MacDonald Australia Pty Ltd. We have been operating in Australia since 1970 (starting with the Melbourne Underground Rail Loop) through an Australian partner which was partially owned by Mott MacDonald up until 2 years ago. We have a strong history in tunnelling and metro projects which extends over 100 years. In the UK, Mott MacDonald have been continually involved with the expansion of London's rail transit systems, with leading roles in the Central Line, Victoria Line, Jubilee Line, Docklands Light Railway, and most recently the rail links to Heathrow Airport and the new Terminal 5 at Heathrow Airport, and now the $30 billion plus Crossrail scheme under London.

Our international metro projects in the past 25 years include Caracas, Singapore and Toronto, and more recently Los Angeles, Delhi, Kaohsiung, Porto, Hong Kong, San Francisco, Dublin, Baku and currently in Australia the Melbourne Metro (business case and concept design, 2010/11).

Previous experience in Sydney includes the design of the land based tunnels of the Sydney Harbour Tunnel, the Shangri-La Hotel built over the City Circle railway tunnels between Wynyard and Circular Quay stations and as the designers of the 2.5km long rock tunnel section and Green Square Station on the Airport Line. We are also currently assisting a developer in obtaining approval for a multi-storey building adjacent to and over Green Square Station.

Mott MacDonald are currently part of a consortium appointed to develop the concept design and business case for the Melbourne Metro.

In Sydney there are examples of piles around tunnels, for example on the Airport Line, with a 10m diameter slurry TBM in soft ground, the elevated roadway at the domestic terminal, the piling works were permissible provided the works were carried out 5m away from the tunnel. The tunnel construction and pile construction were being carried out simultaneously on the same site. The major risk issue was loss of face pressure due to bentonite in the TBM chamber migrating to the pier during their construction (even thou they were never open) and consequent loss of pressure at the TBM face.

At the Shangri-la Hotel site, just north of Wynyard Station and in mass sandstone rock, seven bored piers down each side of the existing tunnel (clearance 1.5m) were drilled with a rock clearance of 1.5m to the "unlined wall of the tunnel". Trains were allowed to run during the bored pier construction works. The maximum pier diameter was 2m and with a depth of 18m. All piers were founded in sandstone rock sockets below rail level.

There are numerous examples of this type of operation in Singapore, Bangkok, Copenhagen and Taipei metro constructions. The existing structures foundation loads are transferred to foundation elements (normally piles or barrettes) that are founded far enough below the tunnel alignment to ensure that any load can be carried by the lengths of those elements that are below the influence line of the tunnels.

The Channel Tunnel Running tunnels run 1.1m apart as they enter the cross- over cavern under the Channel. These are 8.7m tunnels. The second tunnel constructed experienced no difficulties due to the existence of first tunnel. The ground was chalk, a soft rock.

The Channel Tunnel Running tunnels run within 2m of the pumping station caverns at the 25km and 35km marks under the Channel, the running tunnels experienced no additional difficulties due to the existence of the pumping station caverns. Again the ground was chalk.

The running tunnel TBMs for the Bangkok Metro run within 1m of the piles for intersection bridges on Rama IV road, there were no additional difficulties experienced by the running tunnels due to the existence of the piles. The ground was a stiff clay.

Section 9 includes a table of relevant project examples with some details in relation to each of the examples. Technical papers referring to some of these projects have been included in Appendix E, including a paper on the construction of diaphragm walls on the Airport Line where the wall was socketed into the underlying sandstone rock.

3.0 Current Status of R8 & R9 Building Design

Lend Lease have provided the following drawings which include plans and sections of the basement slab, piles and a diaphragm wall (refer Appendix C). The top of the basement slab is at RL -4.5m and the slab thickness is shown as 1.8m over the future Sydney Metro Tunnels. The vertical clearance between the top of the tunnel and the underside of the slab is a minimum of 2m and the actual distance is 5.492m from (down track) tunnel crown to the underside of the transfer slab of Building R9. Piles support the slab and transfer the building loads below the tunnel invert in rock sockets. The as built diaphragm wall (1200mm thick reinforced concrete) panels drawings indicate that the panels were founded with a minimum of 3m rock cover between the tunnel crown and the toe of the diaphragm walls.

#	Drawing No.	Title	Comments
1	161136 – BB1 – SZ_0300011 Rev L	Diaphragm General Arrangement Plan	Plan Diaphragm Wall showing diaphragm wall panels for Sydney Metro Alignment (SMA West) Top of Panels P64 (RL 1.493m); P65 (RL 1.494m); P66 (RL 1.473m; and P67 (RL 1.933m).
2	161136 – BB1 – SZ_0300021 Rev F	West Elevation Sheet 1	West Diaphragm Wall Elevation showing design finish levels of toe of diaphragm wall panels for Sydney Metro Alignment West. Panels P64 (RL -11.4m); P65 (RL -12.0m); P66 (RL-13.50m); P67 (RL -12.80m), with approximately 4.0m (Down Main) and 3.0m (Up Main) rock cover between diaphragm wall panel toe and crown of future Sydney Metro Tunnel. The future Sydney Metro Tunnel spring line and invert is indicated as approximately RL -19.552 and RL-22.938m from Lend Lease. Diaphragm wall toe level to comply with socket criteria actual toe level to be determined during excavation. Stepped/flat panel toes subject to variation based on excavated geology.

#	Drawing No.	Title	Comments
			Socket Criteria panel Numbers P64 minimum 1400mm in Class IV rock or better; P65-P66 Minimum 1000mm in class IV rock or better; P67 minimum 800mm in class IV rock or better. Note 1. Grade III and IV Sandstone rock levels inferred from Menard Bachy in Barangaroo Stage 0 Site Investigations Report (Ref:5020146-QABV-0305-R-00). 2. Position and Level for Future Tunnels are extracted from SD1000011.
3	161136 – BB1 – SZ_0300022 Rev E	West Elevation Sheet 2	West Diaphragm Wall Elevation showing anchor head locations.
4	161136 – BB1 – SZ_0306401 Rev F	As Built - Shop Drawing for D-Wall Panel SMA West (P64 to P68) Elevation Panel 64	Diaphragm Wall Panel 64 Elevation showing Panel Height of 12600mm and thickness of 1200mm. Panel Toe Level RL -11.5m.
5	161136 – BB1 – SZ_0306402 Rev F	As Built - Shop Drawing for D-Wall Panel SMA West (P64 to P68) Details Panel 64	Diaphragm Wall Panel 64 Detail of Reinforcement.
6	161136 – BB1 – SZ_0306501 Rev E	As Built - Shop Drawing for D-Wall Panel SMA West (P64 to P68) Elevation Panel 65	Diaphragm Wall Panel 65 Elevation showing Panel Height of 13900mm and thickness of 1200mm. Panel Toe Level RL -12.9m.
7	161136 – BB1 – SZ_0306601 Rev D	As Built - Shop Drawing for D-Wall Panel SMA West (P64 to P68) Elevation Panel 66	Diaphragm Wall Panel 66 Elevation showing Panel Height of 14500mm and thickness of 1200mm. Panel Toe Level RL -13.4m.
8	161136 – BB1 –	As Built - Shop Drawing for D-Wall	Diaphragm Wall Panel 64 Elevation showing Panel Height of 14000mm

#	Drawing No.	Title	Comments
	SZ_0306701 Rev D	Panel SMA West (P64 to P68) Elevation Panel 67	and thickness of 1200mm. Panel Toe Level RL -13.25m.
9	161804 – BB1 – SD_1000011 Rev 08	Bulk Excavation Wall Elevations Sheet2	Section 5 Western Elevation – Adjacent to Sea Wall. Note Depth of wall to be confirmed pending Metro Tunnel Rock Stress Analysis Panels 2800mm wide.
10	161804 – BB1 – SD_1004003 Rev 02	Bulk Excavation Wall Elevations Sheet3 Walls S-DW-3, 4 & A-DW-5	Section showing approximate depth to base of Diaphragm wall panels and Future Sydney Metro Tunnels.
11	161804 – BB1 – SD_1030026 Rev D	Overall Site Pile Schedule Zone BC5	Schedule of Piles for BC5 Zone and Transfer Slab. Maximum permissible pile set out tolerance is shown. Piles within the Sydney Metro 1st and 2nd reserve are to be sleeved, as determined by Geotechnical Engineer
12	161804 – BB1 – SD_103030031 Rev E	Overall Site Pile Detail Sheet 1	Single Piles for Basement and Podium Columns and for Transfer Raft. Socket Length to be determined by Geotechnical Consultant utilising a rock stiffness finite element analysis. Sleeving level to be determined by Geotechnical Engineer, Refer to Coffey Geotechnical Report GEOLCOV24015AD-EN. Compressible or viscous material to provide vertical and laterial isolation allowing 200mm of Rock movement. Refer to Coffey Geotechnical Report GEOLCOV24015AD-EN.
13	161531 – BB1 – SD_1030032 Rev 00	Overall Site Pile Detail Sheet 2	Structure setout adjacent to future Sydney Metro Tunnel – Typical

#	Drawing No.	Title	Comments
			Section & Plan. 1200mm Exclusion Zone between the transfer piles and the future Sydney Metro Tunnel Alignment includes pile construction tolerances of 200mm. Minimum Distance between Structure & Tunnel to be not less than 1000mm as per Mott Macdonald Report No. 286992 Rev 3.2 Feb 2011. Transfer Structure thickness 1800mm. Minimum Distance between Tunnel Crown and underside of Transfer Structure is 2000mm. Contours show indicative top of rock levels.
14	161804 – BB1 – SD_1030301Rev D	Overall C5 Pile Layout Plane Zone 01	Plan Diaphragm wall alignment across and adjacent to the future tunnels. Diaphragm wall referenced as A-DW1 to A-DW8 and SDW1 to S-DW3. Plan layout of pile locations adjacent to City Metro. Piles spaced at either 6.5m or 13.0m (parallel and perpendicular respectively) along the sides of tunnels.
15	161804 – BB1 – SD_1064001 Rev 00	Basement B2 Subzone 40 Concrete Outline	Plan Basement Concrete Structural Surface Level (SSL): -4.50m. Diaphragm wall alignment parallel to the future tunnels. Diaphragm wall referenced as P49 to P54. Section BC5 SD1000030 is taken across parallel to XQ C501.

#	Drawing No.	Title	Comments
16	161804 – BB1 – SD_1065001Rev 01	Basement B2 Subzone 50 Concrete Outline	Plan Basement Concrete Structural Surface Level (SSL): -4.50m. Diaphragm wall alignment across and adjacent to the future tunnels. Diaphragm wall referenced as P64 to P68 above future Metro Corridor, with thicker section to span across future CBD Metro tunnel corridor.
17	161531 – BC5 – SD_1000030Rev 03	Tower Footing and Core Raft Sections Sheet 1	Cross Section 1 is in drawing 161804 – BB1 – SD_1064001 Rev 00 taken across parallel to XQ C501. Exclusion Zone for Structural elements is indicated. Sydney Metro Protection Zone is shown around proposed tunnels. Sydney Metro Zone of Influence is indicated. Distances from Tunnel Crown to underside of transfer slab are indicated from 5.492m (down track) to 7.520m (up track) and rock cover over crown 0.5m (down track) and 1.5m (up track). Future Tunnel internal radius 2950mm and external radius 3535mm
18	161804 – BB1 – SD_1065021Rev 00	Basement B2 Subzone 50 – Transfer Sections Sheet 1	Cross Section AA and BB Exclusion Zone for Structural elements is indicated. Sydney Metro Protection Zone is shown around proposed tunnels. Sydney Metro Zone of Influence is indicated. Section AA Distances from Tunnel Crown to underside of transfer slab are indicated ranging from 8.591m (down track) and rock cover over crown 2.6m (down track) and 1.9m (up track). Section BB Distances from Tunnel Crown to

#	Drawing No.	Title	Comments
			underside of transfer slab are indicated ranging from 9.185m and 7.851m(down and up track) and rock cover over crown 4.0m and 2.0m (down and up track). Pile sleeve length shown based on Sydney Metro Zone of Influence to be determined by Geotechnical Consultant. Pile Socket Length to be determined by Geotechnical Consultant. Sleeving Length to be determined by Geotechnical Consultant. Future Tunnel internal radius 2950mm and external radius 3535mm
19	161804 – BB1 – SD_1065022Rev 00	Basement B2 Subzone 50 – Transfer Sections Sheet 2	Cross Section CC and Long Section DD Exclusion Zone for Structural elements is indicated. Sydney Metro Protection Zone is shown around proposed tunnels. Sydney Metro Zone of Influence is indicated. Distances from Tunnel Crown to underside of transfer slab are indicated ranging from 16.316m. Pile sleeve length shown based on Sydney Metro Zone of Influence to be determined by Geotechnical Consultant. Pile Socket Length to be determined by Geotechnical Consultant.
20	BB1_PA_R8R9_A101_Issue 3	R8 & R9 Residential Buildings Planning Application – 11_0002 Basement Level 1	Plan Basement Level 1 (Upper) Layout, showing future CBD Metro tunnel corridor. Existing Caisson Wall location shown. Section 1 and 2 shown. Basement Perimeter Retention

#	Drawing No.	Title	Comments
			System. Location for future metro entry and exist portal shown. Vehicle entre and exit to car park shown.
21	BB1_PA_R8R9_A102_Issue 3	R8 & R9 Residential Buildings Planning Application – 11_0002 Basement Level 2	Plan Basement Level 2 (Lower) Layout, showing future CBD Metro tunnel corridor. Section 1 and 2 shown.
22	BB1_PA_R8R9_A201_Issue 2	R8 & R9 Residential Buildings Planning Application – 11_0002 Cross Section 1-1	Longitudinal Cross Section 1-1 East- West Section indicating basement level of -4.5m. Indicative bedrock level. Existing Caisson Structure, Residential Building R8 location. Ground surface level RL3.35m
23	BB1_PA_R8R9_A202_Issue 02	R8 & R9 Residential Buildings Planning Application – 11_0002 Cross Section 2	Longitudinal Section 2 North-South Section indicating basement level of -4.5m. Indicative bedrock level. Residential Building R8 & R9 location. Basement Level Layout, showing future CBD Metro tunnel corridor. Diaphragm Wall forming boundary to foundation works. Future CBD Metro tunnel corridor is indicated below Margaret Street and south edge of Building R9. Exclusion Zone from piles to CBD metro Tunnel System minimum 1.0m
24	GEOTLCOV24015AB	Barangaroo Development Geotechnical Report, Hickson Road, Sydney Plan of Borehole Locations Figure 2	Borehole Locations Plan. Outline of future Sydney Metro Tunnels. Site Boundary. Section CC
25	GEOTLCOV24015AB	Barangaroo Development	Geological Cross Section taken perpendicular to the proposed Sydney

#	Drawing No.	Title	Comments
		Geotechnical Report, Hickson Road, Sydney Section CC	Metro System. Fill over alluvium over Unit 4A/4B Hawkesbury Sandstone Class V and IV Rock over Unit 4C/4D Class III and II Rock.

Table 3 - Comments on current design drawings

The main assumptions underlying the ***Basement Report*** for the R8 & R9 building were as follows:

Future Building over Corridor

- The details of the concept design of Buildings R8 & R9 are sufficiently developed for the purposes of lodging a Project Application. Director General Requirements (DGR's) for Building R8 & R9 were received from the Department of Planning in January 2010. Therefore, the structural frame and founding arrangements applicable to Buildings R8 & R9 have been developed and are presented in this report and included on the drawings. (refer to Appendix C, Structural Foundation Concepts).

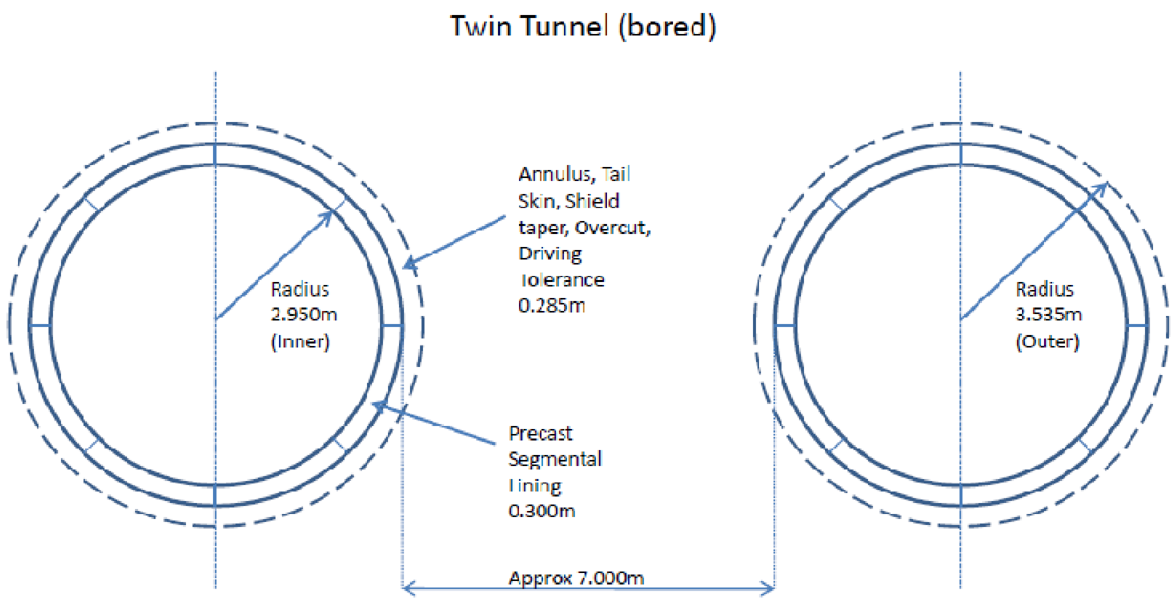
- The Sydney Metro tunnels and station will be constructed after the construction of the critical foundation elements of the Barangaroo basement excavation works, the associated ground water and retentions walls, and the Buildings R8 & R9 within the vicinity of the CBD Metro corridor.

- In the vicinity of the Barangaroo development, the Sydney Metro tunnels will be constructed utilising proven industry standard tunnelling techniques with a shielded Tunnel Boring Machine (TBM) capable of applying adequate pressure to the excavation face to support the active ground pressures where required if it is to excavate a mixed face of soft ground and rock (for example an Earth Pressure Balanced TBM or EPB TBM).

- In the vicinity of the Barangaroo development, the tunnel lining will be of proven industry standard tunnel construction, typically supported by concrete segments. The TBM will push forward from the last erected segmental lining ring. The tunnel lining will be for all practical purposes watertight with gaskets between the segments joints.

- In the vicinity of the Barangaroo development, the TBM excavations will each occupy a corridor of no more than 7.1m in width along the protected alignment. The TBM size has been derived using the information provided in section 1.3.3 of the Metro Works Requirements document that was provided by Sydney Metro which states that '*the clear distance between the centrelines of the Running Tunnels and the tunnel concrete lining is no less than 2.85 and no more than 2.95m in all directions*'. So, using the maximum dimension of 2.95m (i.e. 5.90m diameter), the diameter of the TBM cut profile is assumed to be 7.07m based on the following assumptions:

Running Tunnels internal radius	2.950m
Segmental lining	0.300m
Annulus between the inside of the tail-skin and the segments	0.100m
Tail skin thickness	0.030m
Shield Taper	0.030m
Overcut (including allowance for cutter wear)	0.025m
Driving tolerance (as specified)	0.100m
TOTAL TUNNEL RADIUS	**3.535m**
TOTAL TUNNEL DIAMETER (EXTENT OF TBM CUT PROFILE)	**7.070m**



- The building foundations and subsequent metro tunnels will be constructed by experienced tier 1 construction contractors with expertise in this type of work capable of conforming to detailed specifications and third party supervision and monitoring which is standard industry practice.

- Where required, any future building loads will be transferred past and below the Sydney Metro tunnels as described above and shown on the drawings in Appendix C.

As mentioned above it is assumed that the Sydney Metro tunnel, in the vicinity of the Barangaroo development, will be excavated by an EPB TBM that is capable of applying support pressure to the face. The tunnel support would consist of precast concrete segmental linings erected in rings within the tail skin of the TBM. The annulus between the outside of the ring and the ground created by the initial cut of the TBM will filled continuously by grout and or pea gravel (and then grouted later) as the TBM advances. The assumption of the use of a TBM is made on the basis that the tunnel will encounter significant lengths of soft ground in the tunnel face. This ground would require considerable modification and support if it was to be excavated by other than with a TBM capable of pressurised operation (Slurry or EPB). In sandstone rock alone the loading on the concrete segment ring will be negligible unless there is a localised rock block or wedge movement. In such rock, the main purpose of the concrete ring is to provide a waterproof tunnel, with the gaskets between the segments sealing both the longitudinal and circumferential joints.

It is noted from the rock profile provided by Coffey that the Sydney Metro tunnels below the R9 Residential Building has an increasing thickness of rock cover over the two tunnels crowns from east to west as the tunnels dive to the west. The minimum thickness of rock cover over the tunnel crown below the east side of the R9 Residential Building has an approximate thickness of 0.5m (potentially weathered) and increases to the west to a thickness of 5.5m. The sandstone rock horizon will always be at or above the tunnel crown. This will mitigate the risk of deformations of the linings due to differences in the ground conditions in the top and bottom of the face (please also refer to discussion in Section 7.0). The diaphragm wall (1200mm thick reinforced concrete) panels are founded with approximately 3m of Class III or better sandstone cover between the tunnel crown and the toe of the diaphragm wall.

Any ground loading from the fill and alluvium deposits above the tunnel crown will provide some loading which will be resisted by the passive resistance of the rock at the tunnel crown, sides and below the tunnel invert. This will develop a uniform thrust in the circular segmental ring and some minor bending moments. In accordance with the Metro Specification the concrete segments will be either reinforced with steel bar reinforcement or steel or synthetic fibres.

A review was completed of the **Lend Lease Barangaroo Metro Transfer (West) Structural Design Report for the R9 Residential building (Project No. 160531)** and the following points have been summarised:

- This report covers the Western Section which passes beneath the R9 residential building tower.
- R9 is a 7 storey; 30m tall residential building that will be part of the new development on the Barangaroo site. The Southern end of the tower is located above the transfer and one of the lifts is located on the slab. The road adjacent to the tower is supported by the remainder of the structure. The western portion of the R9 structure lie's outside the extent of the basement and is transferred to piles at ground level.
- Lateral loads for the residential buildings are resisted by the ground and basement slabs strutting into the diaphragm wall. The transfer structure is therefore not required to resist lateral forces.
- Establish a 1 metre minimum clearance between the CBD Metro tunnels and walls, columns or foundation elements. This is in addition to appropriate construction tolerances (nominally 200mm). Where applicable the founding of all vertical structures shall be at a level below the zone of influence of the CBD Metro tunnels (or as agreed). Upon completion of the development there shall be a minimum 2 metres of material above the crown of the future metro tunnels to the slab supporting building C5. The tunnel diameter is taken as 7.07m (Reference [1]). This includes allowance for the annulus, tail skin thickness, shield taper, overcut, driving tolerance and tunnel deformation.
- The tolerance for the position of the pile at the tunnel spring level is conservatively taken as 200mm. This allows for an initial out of position of 50mm and a slope of 1:150. The maximum distance between the existing ground and the spring level is 20.5m, giving a construction tolerance of 187mm. The founding of vertical structural elements is set by the geotechnical engineer (Reference [2]).
- The following principals are also adopted in the design.
    - Provide a continuous flat soffit by using a transfer raft.
    - Use a distribution of small piles that are similarly loaded along the edge of the tunnel.
    - Support any diaphragm wall panels above the railway directly from the transfer structure at the east portal and west boundary line.

- A study into the durability of the basement concrete slabs has determined that the 1.8m structure it will satisfy the 100 year design life. In addition the slab will be isolated from the sea water by a waterproof membrane which will provide additional protection.

- The arrangement of piles results in a very even distribution of forces in the piles along the length of the tunnel. The YY moments for the transfer slab show that it behaves as a one-way spaning structure between the piles. Maximum demand occurs at the western edge of the slab where it is required to support the D-wall in anticipation of future undermining by the tunnel. A 1.8m deep reinforced concrete slab is required to withstand the forces and maintain consistency with the top 1.8m pour of the larger 4m transfer slab.

- The CBD metro transfer (west) has been designed to satisfy the structural design requirements for the CBD Metro.

  - A 1 metre minimum clearance between the CBD Metro tunnels and walls, columns or foundation elements is maintained. This is in addition to appropriate construction tolerances.

  - All vertical structures shall be at a level below the zone of influence of the CBD Metro tunnels through the use of sleeved piles (or as agreed).

  - A minimum 2 metres of material above the crown of the future metro tunnels to the slab supporting building C5 is maintained.

- Detailed analysis of the transfer structure has been undertaken which shows that the pile loads are even and within the structural capacity. A 1.8m deep reinforced concrete transfer raft is required to withstand the forces.

We consider the that the assumptions made for the R8 & R9 buildings are in accordance with the design and construction criteria as accepted by NSW Transport proposed for the buildings over the future Sydney Metro as presented in our report entitled “Barangaroo Development – Protection of the Sydney Metro Corridor” dated 22nd February 2011.

A review was completed of **Menard Bachy Barangaroo Stage 1 Basement Diaphragm Wall Design Report Panel Type Section Sydney Metro Alignment West (Ref:SR030003 rev 3)** and the following points have been summarised:

- Panel Type Section Sydney Metro Alignment (SMA) West (Panels P64 to P68), are located along the western boundary of the perimeter retention system. The diaphragm wall will comprise linear segments (between 3.4m and 6.452m in width) of 1200mm thick reinforced concrete panels with one level of temporary ground anchors and two levels of floor slabs for the permanent case. Each panel will have stop-ends with cast-in water bars to make the panels water-tight and able to withstand full hydrostatic head.

- The diaphragm wall will extend to a minimum depth of 1.4m and 0.8m into Class IV sandstone or better for P64 and P67 respectively. For panels P65 and P66, a minimum of 1.0m into Class IV sandstone or better is required. For P68 a minimum 0.2m into Class III sandstone or 0.5m into Class IV sandstone is required. The socket criteria for wall panels along Sydney Metro Alignment West are shown on drawing SZ0300021.

- Appropriate coupler connections will be provided at the floor slab levels as provided by Lend Lease and starter bars provided at the top of the diaphragm wall to allow connection with the capping beam, to be designed and constructed by others. A selection of drawings for the Section Sydney Metro Alignment West panel P64 to P68 are presented on the as build drawings 161136 – BB1 – SZ_0300021 Rev F to 161136 – BB1 – SZ_0306402 Rev F (Appendix C).

- The rock elevation varies between RL-9.5m and RL-12.1m for Class IV Sandstone and between RL-11.0m to RL-13.6m for Class II Sandstone where encountered refer to the rock elevation drawing SZ0300021 for the inferred rock elevation along section SMA West.

- An assessment of the impact of the future construction of the Sydney Metro Alignment tunnels on the long term performance of the diaphragm wall was completed. The assessment assumed the following:

    - the twin tunnels are to be constructed below the toe of the diaphragm wall with approximately 4.0m of Class III or better sandstone cover between the tunnel crown and the toe of the diaphragm wall;

    - the future Sydney Metro Alignment tunnels will be constructed once the basement and superstructure has been completed;

    - the basement structure has been designed to transfer the superstructure loads from the diaphragm wall in this area to the adjacent diaphragm wall panels, the piles supporting the slabs and the surrounding rock.

- Impact of future SMA Tunnels. The simplified approach adopted to assess the effects of the future tunnels on the diaphragm wall is considered to be worst case and indicates a maximum deflection of the rock immediately below the toe of the diaphragm wall of approximately 7mm.

- It was therefore concluded that construction of the future tunnels may result in additional settlement of the diaphragm wall.

- In the vicinity of the Barangaroo development, the tunnels will be constructed with a shielded tunnel boring machine (TBM) and the tunnel will be supported by concrete segments. It is considered that this tunnel construction method will result in ground movements around the tunnel of less than 10mm in the vicinity of Section Sydney Metro Alignment West.

- The completed basement structure will be reasonably rigid in the vicinity of the future Sydney Metro Alignment tunnels and will be supported on piles that will extend below the invert of the proposed tunnels. The response of the basement structure to the tunnelling induced ground movement will be negligible due to the soil structure interaction effects between the basement structure, the supporting piles and the surrounding ground.

- Given that the diaphragm wall carries no loading in the permanent case, it was assessed that the diaphragm wall will have negligible impact on the future tunnel lining as it will not impose any loading onto the lining.

We consider the diaphragm wall (1200mm thick reinforced concrete) panels founded with approximately 3m of Class III or better sandstone cover between the tunnel crown and the toe of the diaphragm wall would have little effect on a shielded Tunnel Boring Machine (TBM), or future segmental tunnel lining system.

We also consider the that the assumptions made for the **Stage 1 Basement Diaphragm Wall** are in accordance with the design and construction criteria as accepted by NSW Transport proposed for the buildings over the future Sydney Metro as presented in our report entitled “Barangaroo Development – Protection of the Sydney Metro Corridor” dated 22nd February 2011.

A review was completed of **Wilkinson Murray Barangaroo Development Building C5 Ground-Bourne Noise levels from Future Metro Line letter report (10232 Metro VK 120412.doc)** and the following points have been summarised:

- Wilkinson Murray was engaged to assess the potential impact of ground-borne noise from future Metro rail operations upon building C5 in the South Baragaroo development, based on information within the Deed.
- It appears that the vibration levels in the Deed are for the following circumstances, which have been assumed are:
    - In the tunnel wall;
    - For high attenuation track; and
    - At a speed of 90km/h (maximum speed).
- If the Metro is constructed within the proposed rail corridor, then train operations will generate vibration that may affect the proposed C5 commercial building in the South Barangaroo development. As the train moves over the track, vibration will be generated as a result of the interaction between the wheels and the rails and this vibration will be transmitted into the tunnel walls. From here, the vibration can be transmitted into the surrounding ground and up to the foundations of Barangaroo buildings.
- The vibration can be transmitted into the building structure with the possibility of causing perceptible vibration in the floors, but the levels would be well below possible damage criteria. More importantly, the vibrating building elements will result in the radiation of ground-borne noise into occupied spaces, and it is this ground-borne noise that normally has the greatest effect.
- Rail generated ground-borne noise becomes apparent in buildings long before perceptible vibration. Therefore only ground-borne noise is addressed in detail in this report as this is the most stringent noise parameter. That is, if ground-borne noise is controlled to acceptable levels, then vibration will be well below acceptable levels.
- The EA refers to the Interim Guideline for the Assessment of Noise from Rail Infrastructure Projects (IGANRIP (R3)) to determine ground-borne noise criteria for the Metro. This is the best document to refer to for establishing appropriate noise criteria associated with rail operations.
- In accordance with this document, the EA sets “noise trigger levels” above which action is required in regard to noise mitigation. For the purpose of assessing the impact on Barangaroo development, the trigger levels should be taken as criteria of acceptability.
- It is noted that these level are consistent with the Department of Planning’s’ “Development near Rail corridors and Busy Roads – Interim Guideline”. The relevant criterion for the commercial building C5 is 40dBA.

- Ground-borne noise levels have been calculated within the C5 building of the South Barangaroo development based on the following:
    - The vibration source levels indicated in the Deed;
    - No turnouts in the vicinity of the development;
    - No curve radius less than 600m (which will be the case); and,
    - For two scenarios being the eastern diaphragm wall connection and diaphragm wall separation.
- Regenerated noise levels have been calculated in Commercial building C5 and it has been determined that general compliance with the established noise criterion for commercial receivers will be achieved.
- The letter report conclusion stated that on the assumption that the vibration source levels provided in the Deed are not exceeded, groundborne noise levels are expected to generally comply with appropriate criteria at building C5. This finding is based on the levels in the Deed being:
    - In the tunnel wall;
    - For high attenuation track; and
    - At a speed of 90km/h (maximum speed).

We consider that the potential for operational noise and vibration issues associated with the future CBD Metro be addressed by the building designers in the design of the Lend Lease basement for residential R8 & R9 Buildings on the basis that the track in the tunnel itself will be laid on a floating track slab beneath the R8 & R9 Buildings.

4.0 Reference Documents

1. “Development Guidelines within the vicinity of Sydney Metro Network Line 1”, Document No. CBD-2100=PBACH-R-GN-0159, dated 30 March 2010 Rev. A-1.
2. Section 1 - Metro Works Requirements (extract only) and Section 2 Construction Requirements (Extract only) as provided by Department of Transport. (Refer Appendix B)
3. Coffey Geotechnics - Barangaroo Development Plaxis 2D Analysis – Effective Stresses Metro Running Tunnel Protection Zone.
4. ”Barangaroo Development – Protection of the Sydney Metro Corridor” prepared by Mott MacDonald dated 22 February 2011.
5. Coffey Geotechnics “Barangaroo Stage 1 Development Geotechnical Report” Ref: geoteclcov24015AB, dated 15 Oct 2010 (report available from Lend Lease upon request).
6. R9 Building Structural Foundation preliminary design drawings. These are based on the agreed criteria with NSW Transport for the foundations about the tunnel. (Refer Appendix C)
7. Casey & Lowe Pty Ltd, “Non-Indigenous Archaeological Assessment – Barangaroo Stage 1 June 2010.
8. ”Barangaroo Development – The C5 Building over the Sydney Metro Corridor” (Project Reference No. 291284) prepared by Mott MacDonald dated October 2011.
9. “Barangaroo South C5 Commercial Building – Geotechnical Report – Project Application” prepared by Arup Pty Ltd (2 November 2011).
10. Directors General’s Requirements Section 75F of the Environmental Planning Assessment Act 1979 Application Number MP11_0002, Project Residential buildings R8 and R9. Location Hickson Rd, Barangaroo, Sydney (21 January 2010).
11. “Barangaroo Development Building C5 Ground-Born Noise levels from Future Metro Line” (Ref:10232 Metro VK 120412.doc) prepared by Wilkinson Murray (30 April 2012).
12. “Barangaroo South 1A – Residential R8 & R9 Operational & Construction Noise and Vibration Report” (Ref:TF854-01F02 (Rev 2) O&CNVA Report) prepared by Renzo Tonin & Associates (5 October 2012).
13. “Barangaroo Stage 1 – Basement Diaphragm Wall Design Report – Panel Type Section SMA West) (Lend Lease Ref: SR030003 Rev 3) prepared by Menard Bachy (January 2012).
14. Barangaroo Metro Transfer (West) Structural Design Report (Report No: 160531) prepared by Lend Lease (05/10/2012)

5.0 Summary of Relevant Works within the vicinity of the CBD Metro

The proposed Buildings R8 & R9 developments include deep basements with excavation and foundations that include bored piles, retention systems (e.g. secant piled and/or diaphragm walls etc) and possibly barrettes over and adjacent to the future Sydney Metro Line 1 tunnel alignment. The Sydney Metro tunnel corridor will contain two tunnels each with an excavated diameter of approximately 7m separated by a pillar of rock of approximately 7m width**.**

The Barangaroo Development is proposed to be completed in a series of stages. Within the vicinity of the Sydney Metro tunnel alignment, Stage 1B (as defined in the Section 75W modification application) is proposed to overly the CBD Metro corridor for a distance of approximately 120m. Stage 1A (as defined in the Section 75W modification application) of the Barangaroo Development includes a deep basement proposed to be excavated adjacent to the CBD Metro corridor alignment. Bulk excavation works are also proposed over the CBD Metro corridor alignment to the extent indicated in the Section 75W application.

In the vicinity of the future Sydney Metro tunnels the site is bounded by Darling Harbour on the western boundary, Hickson Road on the east boundary and Shelley and Lime Streets on the southern boundary.

The location and type of the basement perimeter ground water control and retention walls are shown on the Section 75W modification application drawings provided by Lend Lease.

With regards to the R8 & R9 Buildings preliminary building foundation drawings are included in Appendix C.

The perimeter diaphragm wall (Panels P64 to P68) in the south-western corner of boundary, is located over the future Sydney Metro tunnels. The diaphragm wall comprise linear segments (between 3.4m and 6.452m in width) of 1200mm thick reinforced concrete panels with one level of temporary ground anchors and two levels of floor slabs for the permanent case. The panels are founded on class IV or better Sandstone rock that range in elevation between RL -11.14m and RL -13.50m. The twin future Sydney Metro tunnels are to be constructed below the toe of the diaphragm wall with approximately greater than 3.0m of Class III or better sandstone cover between the tunnel crown and the toe of the diaphragm walls panels.

Shown on the drawings are a 1800mm deep foundation slab supported by rock sockets piles which will transfer the load below the invert of the tunnel. The final rock socket lengths will be determined during construction by a Geotechnical Engineer. The Structure setout drawing for piling of the transfer structure adjacent to future Sydney Metro Tunnel (drawing 161804 – BB1 – SD_103030032 Rev D) uses the design and construction criteria as accepted by NSW Transport proposed for the buildings over the future Sydney Metro as presented in our report entitled "Barangaroo Development – Protection of the Sydney Metro Corridor" dated 22nd February 2011. The following guidance is indicated on the drawing:

- Exclusion Zone of 1200mm between the transfer piles and the future Sydney Metro Tunnel Alignment including the pile construction tolerances of 200mm.
- Minimum Distance between Structure & Tunnel to be not less than 1000mm as per Mott Macdonald Report No. 286992 Rev 3.2 Feb 2011.
- Minimum Distance between Tunnel Crown and underside of Transfer Structure is greater than 2000mm.

6.0 Guidance on Constraints

The following has been extracted from Section 4.3 (Development Characterisation, Table 4.1) of the "Development Guidelines within the vicinity of Sydney Metro Network Line 1".

Table 1: Summary of Condition Guidelines

Protection Zone		**Construction Activities**	**Conditions Guidelines**
1st Reserve	Inside Protection Zone		Construction not permitted to directly encroach upon Protection Zone ***except where it can be demonstrated to the satisfaction of Sydney Metro that the encroachment will not have unacceptable structural or operational impacts on the metro corridor***.
	Outside Protection Zone	Surface excavation	Engineering assessment required from developer where surface excavations are proposed directly above station caverns and crossover caverns.
2nd Reserve		Surface excavation	
		Foundations	Engineering assessment is not required if calculated bearing pressures are less than 150KPa for shallow footings and strip footings are less than 3m by 3m in plan. For all other shallow foundations an engineering assessment is required of the developer. Engineering assessment is not required from developer if loading from deep foundations (including shaft friction) is transferred to below the boundary of the influence zone. Engineering assessment required from developer where the above condition is not satisfied for deep foundations.
		Underground Excavation (e.g. tunnel/cavern construction), ground anchors and demolition activities.	Developers must demonstrate through an engineering assessment that loading from shallow foundations will not adversely impact the future Line 1 MetroC.
		Geotechnical investigation and directional drilling	Assessment not required.

It is important to note that with the 1st Reserve, inside the protection zone, that penetration of the reserve is acceptable "*where it can be demonstrated to the satisfaction of Sydney Metro that the encroachment will not have unacceptable structural or operational impacts on the metro corridor.*"

7.0 Site Investigation and Geological Profiles

Subsequent to the Sydney Metro's geotechnical investigations, Coffey have undertaken a significant amount of geotechnical investigations to inform the overall Barangaroo South development. With the consent of Department of Transport, geotechnical information prepared for the CBD Metro has been considered and incorporated (where relevant) within the geotechnical report prepared by Coffey for Barangaroo South on behalf of Lend Lease.

A site investigation report for Stage 1 of Barangaroo has been carried out on behalf of Lend Lease Project Management and Construction Pty Ltd (LLPMC) by Coffey Geotechnics Pty Ltd (refer to the list of references in Section 4.0).

The general scope of the work carried out by Coffey's and the topics covered in their report are listed below:

- Verification of the anticipated stratigraphy;
- Detailed assessment of marine/estuarine sediments and potential underlying residual soil;
- Hydrogeological model, including:
  - Verification of water levels across the site;
  - Assessment of the hydraulic conductivity of the geological units;
  - Groundwater ingress/tidal fluctuations;
  - Process for how groundwater will be restricted and removed;
  - Quantum of groundwater to be removed during dewatering process;
  - Impact of the development on existing hydrogeological regime;
- Geotechnical site investigation, report and advice based on the Structural Engineers requirements;
- Seismicity advice;
- Acid sulphate soil potential and soil aggressivity;
- Liquefaction potential of the reclamation fill and granular layers of the marine/estuarine strata;
- Fill material to the rear of the existing caisson wall;
- Material re-use assessment and process for use at Headland Park.

The report describes the investigation works carried out at the site, presents the test results and Coffey's advice on issues relating to basement wall construction, dewatering strategy, bulk excavation issues, foundation design considerations, earth retaining structures and settlement. The report also outlines 'known' and Coffey's perceived risks to the construction phase of the project.

Coffey have included the following in their report:

- Logs of all boreholes, cored boreholes and core photographs drilled as part of the Stage 1 investigation;

  A total of 32 boreholes (including 2 angled boreholes) were drilled during the investigation, comprising 324m of cored drilling and 530m of non-cored drilling. Boreholes were drilled to depths of between approximately 12m and 39m below ground level.
- Design parameters and recommendations for: excavation, rock relief/creep, retention, ground anchors, shallow foundations, deep foundations and durability assessment;
- Hydrogeological model for the site and preliminary hydrogeological assessment of the proposed development including preliminary assessment of the basin inflows;
- Groundwater considerations both during and after construction in relation to retaining wall designs, foundation designs, earthworks and dewatering;
- Retaining wall design parameters including: unit weight of soils, drained friction angles and undrained shear strengths.

The geotechnical investigation and testing was scoped by LLPMC with input from Coffey to provide a general characterisation of the geological and subsurface conditions within Stage 1 of the Barangaroo Development site and to assess the geotechnical constraints which may impact on the proposed design and construction methods.

The geological strata overlying the site can generally be described as fill (Unit 1) overlying estuarine deposits (Unit 2A, as small lenses)) overlying alluvium(Unit 2B) overlying sandstone rock. Please refer to the following tables extracted from the Coffey report for a full description of these and other units.

Mott MacDonald has reviewed the Coffey report and the following boreholes in the vicinity of the Sydney Metro tunnels: BAR14, BAR15, BAR24, BAR31 and BAR32. Together with the long section prepared by Lend Lease Design (refer Appendix D) showing the geological profile it would appear that a TBM excavation would predominately be in fresh rock and perhaps up to 25% of the face may be in moderately to slightly weathered rock.

As stated by Arup in November 2011 that 'it is likely that remnant foundations and other underground elements remain in-situ from many of these former structures including; wharf structures, historical dock walls, building foundations, etc".

The extent of the R8 & R9 buildings foot print is shown in plan on the drawings in Appendix C with the rock profile plotted on Sections A-A, B- B, C-C and D-D. In Appendix D the extent of the building has been superimposed on the geological long section.

Also included in Appendix D are additional sections of the tunnel with a basic geological profile showing the Fill and Alluvium (soft ground) overlying the sandstone rock horizon. Reviewing the above boreholes logs together with the drawings, it would appear that in this area of the site the soft ground either overlies a maximum of 2m of highly weathered sandstone rock overlying slightly weathered to fresh sandstone rock (class IV /III).

The SPT counts in the soft ground vary significantly between boreholes range from consistently low and in some borehole consistently high and even some to refusal.

Unit	Approx Depth to Top of Unit (m)	Approx. Thickness (m)	Description
1. Fill	0.0m	<10 to 15, typically less than 14 above the Metro Tunnel	Mixtures of clay, sand and gravel in variable proportions derived mainly from crushed and/or ripped Sandstone, with a variety of materials including brick, concrete, rubble, wood, glass and slag. Filling of the wharf areas varied from natural soils and rocks (likely excavated from building basements and tunnels and dredged from the adjacent harbour) to demolition and waste materials. The fill may contain large boulders, timber and possibly buried wharves, timber piles, boats and other abandoned infrastructure. Large voids have also been identified (discussed in Section 4.1). The fill thickens towards the west of the Stage 1 area resulting from progressive infilling from the east to form the wharf and the natural rock surface stepping down markedly in a westerly direction. The base of the fill has been interpreted as highly irregular and has often mixed with the upper surface of the underlying natural soil during placement.
2B. Alluvial Sediments	11.0m to 16.0m	1m	Typically sand dominated (primarily silty sands and clayey sands with some cleaner sand horizons) with subordinate and interbedded silty clays and sandy clays. Inferred to be derived from weathered sandstone from neighbouring sandstone highland. Typically exhibit brown, orange brown, red brown and yellow hues attributed to aerial exposure and oxidation resulting from a time of low sea level during the last glacial period of the Pleistocene Epoch. This period of low sea- level would have promoted down-cutting of river systems into the underlying bedrock and infilling of these channels with alluvial sediments. Unit 2B sediments are typically medium dense to dense sands with subordinate firm to very stiff (typically stiff) clays.

Table 7A: Description of fill and estuarine sediment units

Unit	Approx Depth to Top of Unit (m)	Approx. Thickness (m)	Description
4. Sandstone	10 to 15	1 to 2.5m	Extremely low strength and extremely to highly weathered close to the top of the unit grading to high strength and fresh at depth (refer to Table 4.2).

Table 7B: Description of remaining units (Table 7C Sandstone Classes)

Unit	Depth to top of unit below bedrock surface (m	Description
4A. Class V Sandstone	0 to 3.75 (typically less than 1.0 where present)	Extremely low to low strength, extremely to highly weathered, frequent zones of clay seams, highly fractured or fragmented. At most locations, Unit 4A has been eroded and no longer exists,
4B. Class IV Sandstone	0 to 2.0 (typically 1 to 3 where present)	Low strength, highly weathered, significant clay seams, fractured. Typically highly permeable. May also occur within Unit 4C as more weathered and fractured sandstone or sandstone containing shale and laminite lenses. Unit 4B may also have been eroded in some locations so that Unit 4C occurs directly below the eroded bedrock surface.
4C. Class III Sandstone	0 to 3.5 (typically 0.5 to 2)	Medium to very high strength, slightly to moderately weathered, fractured. May occur as more fractured/weathered zones within the lower Unit 4D
4D. Class II Sandstone or Better	0.5 to 3.5 (typically 2 to 5)	Medium to very high strength, fresh to slightly weathered, slightly fractured to unbroken.

Table 7C: Summary of Sandstone Profile (refer Coffey report)

8.0 Risk and Engineering Assessment

8.1 Risk Assessment Methodology

Based on the proposed design as detailed in the Bulk Excavation and Basement Car Parking Section 75W modification application (Part A) together with the Buildings R8 & R9 Generic Structural Foundation Concepts (Part B), and as required under the Guidelines, a risk assessment has been undertaken.

Section 5.3 of the Guidelines provides Preliminary Risk Definitions that are recommended to be used in an Engineering Assessment. In order to be able to include a broader range of risk assessment, Mott MacDonald has chosen to use AS/NZ 4360:2004 using the Risk Consequence, Likelihood and Matrix Tables 10A,10B and 10C as outlined below for both Part A and Part B. The most recently published risk standard, AS/NZS ISO 31000:2009 which is based on AS/NZ4360:2004 allows the development of a projects own specific risk assessment tables.

Table 8A: Likelihood Ratings

Likelihood	Category	Description
Almost Certain	A	The event is expected to occur in most circumstances
Likely	B	The event will probably occur in most circumstances
Possible	C	The event should occur at some time
Unlikely	D	The event could occur at some time
Rare	E	The event could occur only in exceptional circumstances

Table 8B: Risk Consequence Descriptors

Consequences	Category	Description
Catastrophic	5	The consequences would threaten the event and the event organisation. e.g. death, huge financial loss
Major	4	The consequence would threaten the continued effective functioning of the event organisation and therefore the event e.g. major financial loss, important external resources required.
Moderate	3	The consequences would not threaten the event, but would mean that the event would be subject to manageable changes e.g. high financial loss, medical treatment required.
Minor	2	The consequences would not threaten the efficiency or effectiveness of some aspects of the event, but would be dealt with internally e.g. medium financial loss, first aid treatment.
Insignificant	1	Consequences would be dealt with by routine operations, e.g. no injuries, no financial loss.

Table 8C: Level of Risk Matrix

Likelihood	Consequence				
	1 Insignificant	2 Minor	3 Moderate	4 Major	5 Catastrophic
A Almost Certain	Moderate	High	High	Extreme	Extreme
B Likely	Moderate	Moderate	High	High	Extreme
C Possible	Low	Moderate	High	High	High
D Unlikely	Low	Low	Moderate	Moderate	High
E Rare	Low	Low	Moderate	Moderate	High

Protection Corridors are set up around metro systems prior to construction principally to ensure that the alignment for the future the metro does not become occupied by other structures. They are set up around constructed metros to manage the much more significant risks to the metro associated with subsequent constructions close to the metro structures. As previously stated this report assumes that the Barangaroo South Development described in this report is constructed prior to the Sydney Metro.

8.2 Risk Assessment

The Bulk Excavation and Basement Car Park MP10_0023, and the Buildings R8 & R9 Generic Structural Foundation Concept risks are identified in separate tables.

The risks for Parts A and B have been assessed as part of the one table due to the fact that many of the risks are the same.

It is important to note that where a risk has been identified corresponding mitigation measures have been described that reduce the risk.

Table 8D: Risk Assessment Table

#	Description	Likelihood	Category	Risk (L,M,H,E)	Mitigation	Likelihood	Category	Risk (L,M,H,E)	Comments
1	Potential for bulk excavation to adversely impact on surrounding rock mass due to changes in the in-situ stresses.	B	1	M	It is highly unlikely that any changes in ground stress or displacement caused by the excavations will have any impact whatsoever on the future tunnelling works (in fact the basement excavation will decrease the potentially high theoretically existing predicted horizontal ground stresses). Any movements due to the Barangaroo basement excavations will occur at the time of those excavations and prior to the commencement of the Sydney Metro tunnelling works. Sydney sandstone is classed in tunnelling terms as a soft rock(UCS < 100MPa) and a TBM would have no difficulty cutting this rock either in a highly fractured state or in the form of massive rock mass without defects or displacements across these defects. Coffey has demonstrated through theoretical modelling that the changes in in-situ rock stress distribution are largely independent of the proximity of the Lend Lease basement wall to the tunnel.	E	1	L	Negligible risk to future tunnel. Refer also to Coffey Geotechnics memo report and analysis.
2	Temporary ground anchors supporting retention walls or retention piles intersect the tunnel alignment.	C	3	H	Design temporary ground anchors that are required as part of the Lend Lease basement perimeter ground water control and retention system works so that they do not intersect the future running tunnels. Modern anchor design permits a wide variety of anchor lengths, configurations and	E	2	L	Negligible risk

#	Description	Likelihood	Category	Risk (L,M,H,E)	Mitigation	Likelihood	Category	Risk (L,M,H,E)	Comments
					orientations. Accurately survey the drilled position of the ground anchor hole using down-hole survey instrument before placing ground anchor and grouting. The accurate positioning of ground anchors is considered standard practice using proven industry techniques.				
3	Adverse effect of the Lend Lease basement works on the existing permanent ground water table.	D	2	L	The Lend Lease basement perimeter ground water control and retention wall (diaphragm wall or equivalent) will control ground water ingress so that the existing long term water level will be largely unchanged. The construction of perimeter retention systems to control groundwater inflow is conventional engineering practice.	D	2	L	The position of the ground water table whether retained or amended through the retaining works will not significantly change the already existing risk with respect to ground water.
4	Loss of surcharge above the tunnel due to basement excavation.	C	3	H	The Lend Lease prepared Generic Structural Foundation Concepts propose the retention of a minimum of 2m above the tunnels in all cases which will provide sufficient surcharge for the TBM construction.	E	1	L	The ground above the tunnel is also confined by the overlying transfer structure.
5	Ravelling of ground (soft or rock) at the TBM face.	C	2	M	A Slurry or EPB TBM is designed specifically to prevent ravelling in front of the TBM face. In the unlikely event that ravelling occurs the TBM will traverse through that area of ground and any subsequent void remaining behind	C	2	M	This risk remains regardless of whether the Barangaroo development is there or not.

#	Description	Likelihood	Category	Risk (L,M,H,E)	Mitigation	Likelihood	Category	Risk (L,M,H,E)	Comments
					the segmental lining will be filled.				
6	Risk of TBM departing from the design alignment such that there is the potential to conflict with Building R9 foundation transfer piles, or the basement perimeter walls.	D	4	M	Allow a 1m clearance in addition to tunnel and Lend Lease's structural tolerances. Industry standard tolerances on metro tunnel construction range from + or - 50mm in Singapore up to + or – 70mm used in Bangkok. Therefore the 100mm tolerance allowed in the Metro specification is considered readily achievable. Modern TBMs use computerised guidance systems that give very clear indications of where the TBM is in relation to the design alignment. These systems can be set up to sound alarms both on the TBM and in the supervision (Contractor and Owner) offices if the TBM deviates from the required alignment or is likely to deviate so that the TBM alignment can be corrected. The control and management of the tunnel alignment to maintain design tolerances using conventional TBM technology is considered standard industry practice.	E	4	L	Risk reduced because of mitigation measures described. Advance rate of TBM relatively slow so that the mitigation measures described in the construction phase would be effective.

#	Description	Likelihood	Category	Risk (L,M,H,E)	Mitigation	Likelihood	Category	Risk (L,M,H,E)	Comments
7	Risk of Lend Lease's Building R9 or the basement foundations including the perimeter ground water control and retention walls being constructed outside the design tolerances (that have been agreed with Sydney Metro).	D	4	M	Coordinate the Sydney Metro and Barangaroo survey grids and certify survey set out by registered surveyor. Utilise modern three dimensional CAD software for the design and coordination of the Lend Lease basement foundations including the perimeter ground water control and retention walls and the CBD Metro tunnel alignment. This software is considered standard practice for modern major infrastructure and development projects. Require Australian Standard construction tolerances for the piling works (as a minimum). Ensure during construction of the basement foundations including the perimeter ground water control and retention walls that they are constructed within the specified toleran**ces.** Before lowering steel reinforcement cages and backfilling with concrete have independent check of pile/diaphragm wall vertical alignment and depth. This is managed through suitable quality control processes. Mark the tunnel outline on the ground	E	4	L	Risk reduced because of mitigation measures described.

#	Description	Likelihood	Category	Risk (L,M,H,E)	Mitigation	Likelihood	Category	Risk (L,M,H,E)	Comments
					surface. When working within the vicinity of the CBD Metro alignment, workers should be inducted to ensure awareness. Produce three dimensional 'Works as Executed' drawings to Sydney Metro for future tunnel design and construction coordination.				
8	Stresses induced by the Barangaroo basement foundations including the perimeter ground water control and retention walls, and Building R9 structures adversely affect the Metro tunnels, as foundation elements cause localised high stresses that exceed the capacity of the tunnel linings.	C	4	H	Ensure that all foundations transfer the building loads to such a depth that any future tunnel is not affected. The use of modern three dimensional CAD software for the design and coordination of the Lend Lease basement foundations including the perimeter ground water control and retention walls and Building R9 and the CBD Metro tunnel alignment will ensure that foundations are located at appropriate depths. This software is considered standard practice for modern major infrastructure and development projects. Pile liners can be used to manage the extent	E	1	L	Risk is actually removed because of mitigation measures described.

#	Description	Likelihood	Category	Risk (L,M,H,E)	Mitigation	Likelihood	Category	Risk (L,M,H,E)	Comments
					of pile skin friction or otherwise. Pile liners considered standard industry practice for piling in water charged ground. Ensure during construction of the basement foundations including the perimeter ground water control and retention walls that they are constructed to the specified depths. Before lowering steel reinforcement cages and backfilling with concrete have independent check of pile/diaphragm wall depths. This is managed through suitable quality control processes. Produce three dimensional 'Works as Executed' drawings to Sydney Metro for future tunnel design and construction coordination.				
9	Elastic movements of the Barangaroo structures causes instability in the tunnel walls when the tunnels are driven past the walls at less than earth pressure balance pressures. (This is generally only a significant risk when going past particularly flexible structures in soft ground)	D	2	L	It is not a significant risk in the sandstone rock or soft ground for the type of TBM assumed and for a segmental concrete lining as described. However, the rigid retaining structures adjacent to the tunnel alignment will not move or the movements will be so small they will be insignificant.	E	1	L	Refer to drawings provided in Appendix D.
10	TBM breaks down under the	D	3	M	Use a TBM that can have component parts (in	E	1	L	Risk reduced by using

#	Description	Likelihood	Category	Risk (L,M,H,E)	Mitigation	Likelihood	Category	Risk (L,M,H,E)	Comments
	Barangaroo structures and needs to be repaired or recovered.				particular, the main bearing) replaced from within the completed tunnel. TBMs of this design feature are readily available from reputable TBM manufacturers. Use a TBM that can have component parts that can be fully recovered if required from within the completed tunnel.				appropriate TBM design.
12	Loss of overlying soft ground at the tunnel face that cannot be managed due to the presence of the surrounding Barangaroo structure.	D	2	L	Use a TBM capable of operating in a pressurised mode to provide the required face support to the soft ground. If there is for some reason excessive face loss at the tunnel face the TBM should be run through this ground and the void grouted once the TBM has cleared the area. Grouting will not be affected by any surrounding structures. The TBM is run through with grouting to follow so that the TBM is not accidently grouting into the ground itself.	E	1	L	The piled foundations supporting Building R9 will actually improve the ground conditions surrounding the tunnels. In one of the Lend Lease Generic Structural Foundation Concepts the 1.2m diameter steel reinforced concrete piles spaced at 5m centres along both sides of each tunnel will act as ground reinforcement in both the sandstone and soft ground above the rock horizon both vertically and horizontally.
13	Change in groundwater regime due to Barangaroo Development adversely affects the Metro project	E	1	L	It is unlikely that the Barangaroo development will either significantly raise or lower the existing tidal groundwater table in the longer term, therefore no no adverse impact for the Sydney Metro project is expected.	E	1	L	An EPM TBM can operate effectively both above and below the ground water table.

#	Description	Likelihood	Category	Risk (L,M,H,E)	Mitigation	Likelihood	Category	Risk (L,M,H,E)	Comments
14	Loss of the overlying soft ground at the tunnel face to such an extent that a large void is formed that migrates to the surface causing traffic disruption or damage to surface structures.	D	3	M	The structural concept for the Barangaroo basement and Building R9 over the future tunnels is for a suspended structural element on piles with a minimum clearance of 2m. The suspended structure would eliminate this risk of a void migrating to the surface and would be unaffected by voiding over the tunnel. The structural design and construct criteria for the suspended structural elements above the CBD Metro tunnel and their support piles can be the subject of ongoing design approvals with Sydney Metro as part of the design review process.	E	1	L	Risk removed because of mitigation measures described.
15	Flotation of the tunnel lining if there is insufficient surface ground cover above the tunnel together with a high water table.	D	4	M	Where the ground cover is less than approximately 10m a calculation check must be carried out to confirm that the tunnel lining will not be subject to excessive flotation uplift forces. This is particularly relevant where there is open ground above the tunnel. In contrast under the R9 building the proposed 1.8m thick suspended slab and building load above will confine the ground under the slab and prevent flotation of the tunnel.	E	4	M	The risk under the building does not exist in this particular situation, in open ground within the Barangaroo site boundary, design measures may have to be taken if calculations demonstrate that without them there is a risk of flotation of the tunnel lining.

8.3 Engineering Assessment

Section 5 of the Sydney Metro Development Guidelines refers to seven generic items requiring Engineering Assessment for development proposal in the vicinity of the Metro alignment. The seven items from the Guidelines are repeated in full in the table following in this section with comments as necessary and reference to the risk tables where made.

Table 8E: Engineering Assessment

#	The Engineering Assessment should address the following	Comments	Further reference in this report and risk table
1	Changes in stress distribution within the ground above or surrounding planned metro underground infrastructure as a consequence of development construction. Of particular interest is the increase in vertical and horizontal pressures beneath foundation elements and increase in shear along existing bedding planes in the rock mass.	The current sequence of development at Barangaroo contemplates the construction of the Sydney Metro station and tunnels after the construction of the critical foundation elements of the Bulk Excavation and R8 & R9 Buildings works at Barangaroo South. Bulk excavation has the greatest potential to change the existing surround stress distribution in the rock mass, however, with Bulk Earthworks being undertaken prior to the development of the Sydney Metro as part of MP 10 0023, no changes of stress conditions subsequent to the development of the Sydney Metro arising from the development of Barangaroo South are expected. Bulk Earthworks undertaken as part of MP 10 0023 and Building works associated with R8 & R9 Buildings are proposed to utilise standard engineering and construction methodologies and equipment. Bulk Earthworks undertaken as part of MP 10 0023 and Building works associated with R8 & R9 Buildings will therefore not affect the ability of the TBM to excavate tunnel in sandstone rock and mixed face.	Risk item 1 Risk item 10.

#	The Engineering Assessment should address the following	Comments	Further reference in this report and risk table
		Basement perimeter groundwater control and retention wall and R8 & R9 Buildings loads will not be imposed on the future tunnel lining and will generally be designed to be founded below the tunnel	
2	Changes to the groundwater regime, including dewatering works or the installation of barriers to groundwater flow that may dam groundwater above the underground infrastructure.	The current sequence of development at Barangaroo contemplates the construction of the Sydney Metro station and tunnels after the construction of the critical foundation elements of the Bulk Excavation C5 Building and R8 & R9 Buildings works at Barangaroo South. The Lend Lease basement perimeter ground water control and retention wall will use industry standard wall types such as diaphragm wall or equivalent and will control ground water ingress so that the existing long term tidal water level will be largely unchanged. It is unlikely that the Barangaroo development will either significantly raise or lower the existing tidal groundwater table in the longer term, therefore no adverse impact for the Sydney Metro project is expected.	Risk item 4.
3	Increase in structural actions, such as axial loading and flexural bending, to support elements and structural linings of the metro underground infrastructure, as a consequence of development loading.	The current sequence of development at Barangaroo contemplates the construction of the Sydney Metro station and tunnels after the construction of the critical foundation elements of the Bulk Excavation and R8 & R9 Buildings works at Barangaroo South. The likelihood of increase in structural actions, such as axial loading and flexural bending, to support elements and	Refer to Generic Structural Foundation Concepts in Appendix C. Risk item 2 and item 3. Risk item 9.

#	The Engineering Assessment should address the following	Comments	Further reference in this report and risk table
		structural linings of the metro underground infrastructure, as a consequence of development loading is negligible. Where required, structural elements of the Barangaroo South development will be designed using industry standard techniques and design practices to appropriately transfer loads either into the rock mass or past the tunnel. The development of design and construct criteria and design guidelines to be agreed between Sydney Metro and Lend Lease will be used to manage risks of tunnel construction subsequent to development of Barangaroo South.	
4	Deformation of the tunnel and cavern support elements and the surrounding ground. Of particular interest is the potential for encroachment of the structural lining into the contained envelopes (e.g. structure gauge etc), as well as predicted movement along existing bedding planes and their consequent effect on the support elements (e.g. rock bolts).	The current sequence of development at Barangaroo contemplates the construction of the Sydney Metro station and tunnels after the construction of the critical foundation elements of the Bulk Excavation and R8 & R9 Buildings works at Barangaroo South. Where required, structural elements of the Barangaroo South development will be designed using industry standard techniques and design practices to appropriately transfer loads either into the rock mass or past the tunnel such that deformation of the tunnel and cavern support elements and the surrounding ground is unlikely during the Metro works subsequent to the Barangaroo South development. The development of design and construct criteria and design guidelines to be agreed between Sydney Metro and	Risk items 7 and 8.

#	The Engineering Assessment should address the following	Comments	Further reference in this report and risk table
		Lend Lease will be used to manage risks of tunnel construction subsequent to development of Barangaroo South. A pattern of bored piers along and adjacent to the tunnels will in effect reinforce the rock mass. Above the rock profile similarly the piles will be of benefit, though this is difficult to quantify.	
5	Associated excavation methodology, especially where methods employ rock blasting, chiselling, percussive piles driving or similar methods are proposed.	The current sequence of development at Barangaroo contemplates the construction of the Sydney Metro station and tunnels after the construction of the critical foundation elements of the Bulk Excavation and R8 & R9 Buildings works at Barangaroo South, therefore impacts on Sydney metro arising from excavation methodology, especially where methods employ chiselling, percussive piles driving or similar methods are proposed are not relevant. Blasting is not to be used.	N/A
6	In circumstances where developments are likely to have a significant impact on the future construction of the SMN-Line 1 Metro a comprehensive assessment is needed that should involve the use of numerical modelling to accurately predict imposed actions to the support elements of the metro infrastructure. These types of assessment will generally be required for development in the First (1^{st}) Reserve where excavation, or pile driving, will be relatively deep and close to the metro infrastructure and/or foundation	The current sequence of development at Barangaroo contemplates the construction of the Sydney Metro station and tunnels after the construction of the critical foundation elements of the Bulk Excavation and R8 & R9 Buildings works at Barangaroo South. Barangaroo South will not impact on the future construction of the Sydney Metro tunnels. Any imposed loadings will be at the agreement of Sydney metro as part of the approvals process. All piles with transfer load past the tunnel.	Refer to Generic Structural Foundation Concepts in Appendix C. Construction clearances and hence construction tolerance are regarded as the most likely risk for the Sydney Metro tunnels. This is has been addressed by providing adequate clearance as referred to in other sections.

#	The Engineering Assessment should address the following	Comments	Further reference in this report and risk table
	loading from the development is significant.	The development of design and construct criteria and design guidelines to be agreed between Sydney Metro and Lend Lease will be used to manage risks of tunnel construction subsequent to development of Barangaroo South.	
7	Where developments are expected to be of less concern, such as the case of construction only within the Second (2^{nd}) Reserve, engineering assessments need not be as detailed. These types of assessment might only involve estimation of indicators such as stress changes and deformation within the ground from construction. These types of assessment may involve the use of less rigorous modelling techniques.	The development of design and construct criteria and design guidelines to be agreed between Sydney Metro and Lend Lease will be used to manage risks of tunnel construction subsequent to development of Barangaroo South. Refer above.	Refer above.

As demonstrated by our risk assessment, there are low risks to the Sydney Metro tunnels and structures due to the Buildings R8 & R9 Development and associated structures if that development precedes the construction of the CBD Metro. The potential risks that do exist are related to geometric setout (i.e. site survey control) and construction conformance (to expected tolerances) more so than design (i.e. issues related to rock stresses). In each case mitigation measures have been proposed and these are generally industry standard.

Based on the analysis contained in this report, it is Mott MacDonald's opinion that the establishment of a 1.0 metre minimum clearance between all proposed building basement ground water control and retention wall and buildings R8 & R9 foundation structures would be an appropriate building design control to further mitigate any risks. The construction tolerances for these elements (basement and Buildings R8 & R9) are in addition to the 1 metre minimum clearance.

At this stage only noise and vibration have been identified as a potential operational issue for the building alone and which must be addressed by the building designers. We assume that the track in the tunnel itself will be laid on a floating track slab.

As reflected in the Lend Lease prepared Structural Foundation Preliminary Design Drawings (refer Appendix C), we believe that the key components of an acceptable structural design and construct criteria and design guidelines would include the following:

- The establishment and adoption of an integrated survey grid between the Lend Lease development at Barangaroo South and the CBD Metro including the subsequent verification of Works as Executed drawings.

- The establishment of a 1 metre minimum clearance between the CBD Metro tunnels and walls, columns or foundation elements associated with Bulk Excavation and Basement Car Parking (MP10_0023) and Buildings R8 & R9 (MP11_0002). This is in addition to appropriate construction tolerances.

- Where required, the founding of all vertical structures associated with the Bulk Excavation and Basement Car Parking MP10_0023 and Buildings R8 & R9 (MP11_0002) at a level below the zone of influence of the CBD Metro tunnels (or as agreed).

- Upon the completion of the Barangaroo South development, all the ground above the crown of the future metro tunnels under the slab spanning between the piles supporting Buildings R8 & R9 is retained. The minimum clearance from the underside of the slab to the crown of the Sydney Metro tunnel will be 2m.

There are many examples both within Australia and internationally of tunnels being constructed in close proximity to existing structures with no negative effects on the tunnels as per examples in Section 9.0.

9.0 Relevant Examples

We have demonstrated the feasibility of the proposed works in the previous sections of this report and which also includes a risk analysis. The following table is a selection of similar projects to illustrate that this type work has been carried out previously and successfully before.

Tunnelling Under Existing Buildings – Using a slurry or EPB TBM						
#	**Project**	**Description**	**Ground Conditions**	**Tunnelling Method**	**Building foundation description**	**Reference Source**
1	Airport Line - Sydney Airport (1995 – 2000)	Domestic Terminal, tunnelling under existing 5-storey car park and also under a new car park designed to accommodate the new tunnel to traverse beneath.	Saturated sands with a near surface water table.	A 10m diameter slurry TBM with 450mm a thick concrete segmental liner. The ground cover to the crown of the tunnel was 12m along this section of tunnel.	8m long friction piles in sand. Multiple piles under each building column. The TBM passed below the piles with a 4m vertical clearance. The old car park has five floors and the new car park was initially built with five floors with four floors added around 2005.	Experience on the project. Also refer to paper published in 1999 regarding tunnelling under airport airside. Appendix E
2	Taipei Metro-Jonghe Line 1994-95	Twin metro tunnels under various buildings of 4 to 6 storeys	Mixed ground of clay/sand and gravel	Tunnels were built using a 6.3m diameter EPB TBM	Shallow friction piles were used under these buildings.	Experience on the project.
3	Bangkok Metro – Initial project 1999	Twin metro tunnels under road bridges along the alignment under Thanon Asoke	Soft to stiff clay	Bridges were on friction piles founded below the tunnel. Piles in alignment were removed after the bridge had been underpinned. Tunnels were built using a 6.3m diameter EPB TBM	Deep friction piles were used under these bridges.	Experience on the project
4	Lisbon Metro- Rossio – Cais do Sodre metro extension	Metro tunnels passing at low cover under a 19th century masonry building that had been underpinned	Mixed face of clay and granular fill	Tunnels were built using an EPB TBM	Building was on pads and short piles,	Lisbon Metro – Strengthening of buildings above the tunnels in the city center. J. Moreira and A. Floor - Proceedings ITA World Tunnel Conference

						1998,

Tunnelling Under Existing Buildings – Using a slurry or EPB TBM						
#	**Project**	**Description**	**Ground Conditions**	**Tunnelling Method**	**Building foundation description**	**Reference Source**
5	Circle Line 5 – Singapore 2009	Twin metro tunnels under a 15 storey building	Weathered to completely weathered mudstones and fill (mixed)	Building was on piles, it was underpinned so that the piles in the tunnel alignment could be disconnected. Clearances to new piles were less than 1m for the tunnel drives, that were built using a 6.2m diameter EPB TBM	1.5m bored piles were in place. The underpinning used barrettes to support the transfer structure. Existing piles and barrettes were founded below tunnel spring line, and imposed no loads on the tunnel lining	Experience on the project.

Building Excavation Around Existing Tunnels						
#	**Project**	**Description**	**Ground Conditions**	**Tunnelling Method**	**Building foundation description**	**Reference Source**
1	ANA Hotel – "The Rocks" Sydney. Now called the Shangri La Hotel.	35 storey hotel with deep basement constructed over and adjacent to the twin track rail tunnel between Wynyard and Circular Quay.	Class I and II Sydney Sandstone	Tunnel constructed in the 1930s, probably drill and blast with unreinforced concrete arch over crown and un-support vertical rock side walls.	Seven bored piers drilled down both sides of tunnel 1.5m from rock face of inside wall of tunnel. Largest bored pier 2m in diameter and 18m in depth. All founded below rail level in rock sockets. Excavation within 3m of the tunnel crown. 2.5m deep concrete transfer slab over the tunnel.	Experience on project. Paper published 1990. Appendix E

10.0 Conclusions and Approvals

This report supports a Project Application (MP11_0002) submitted to the Minister for Planning pursuant to Part 3A of the Environmental Planning and Assessment Act 1979 (EP&A Act). The Application seeks approval for construction of two residential flat buildings (known as Buildings R8 and R9) and associated works at Barangaroo South as described in the Overview of Proposed Development section of this report. This report follows the NSW Transport accepted construction criteria proposed for the buildings as presented in our report dated 22nd February 2011 which concentrated on objectively reviewing the requirements of the "Development Guidelines within the vicinity of the Sydney Metro Network Line 1" of March 2010, Rev. A-1 in the context of development proposed by Lend Lease at Barangaroo South as described under the Basement and Bulk Earthworks Project Application MP 10 0023 and subsequent proposed amendments under 75W application and a proposed future C5 Building Project Application contemplated by DGR's MP 10_0227.

The Development Guidelines are heavily weighted towards design and operational impacts within the Protection Zone, 1st Reserve, although the seven items required by Sydney Metro for engineering assessment do not specifically mention operational issues.

At this stage only operational noise and vibration issues have been identified as potential issues to be addressed by building designers in the design of the Lend Lease basement and R8 & R9 Building and on the basis that the track in the tunnel itself will be laid on a floating track slab, we believe noise and vibration impacts are manageable.

With reference to the Lend Lease prepared Structural Foundation Preliminary Designs and the proposed structural design and construction criteria (agreed with Department of Transport), encroachments arising out of the Bulk Excavation and Basement Car Parking MP10_0023 and Buildings R8 & R9 MP11_0002, the commensurate structural loads, and the resulting geotechnical conditions, it has been demonstrated that ***"…encroachment will not have unacceptable structural or operational impacts on the metro corridor"*** *a*nd hence ***"will not impede the metro rail corridor or affect the future operations of the metro project…"*** as required by the relevant Director General's Requirement.

The proposed key elements of the structural design and construct criteria are:

- The establishment and adoption of an integrated survey grid between the Lend Lease development at Barangaroo South and the CBD Metro including the subsequent verification of Works as Executed drawings.
- The establishment of a 1 metre minimum clearance between the CBD Metro tunnels and walls, columns or foundation elements associated with Bulk Excavation and Basement Car Parking MP10_0023 and Buildings R8 & R9 MP11_0002. This is in addition to appropriate construction tolerances.
- Where required, the founding of all vertical structures associated with the Buildings R8 & R9 MP11_0002 at a level below the zone of influence of the CBD Metro tunnels (or as agreed). The preliminary design shows the piles with their sockets founded below the tunnel invert.

- The piles sleeving length is to be determined by Geotechnical Consultant based on Sydney Metro Zone of Influence. However, if we assume that the piles are not isolated from the rock above the tunnel invert. Firstly, the steel reinforced bored concrete piles are stiffer than the surrounding rock which will facilitate the direct transfer of load through pile rather than into the rock. Secondly, if the rock is disturbed adjacent to the pile above the tunnel invert during tunneling by the TBM this principle of load transference to the rock socket below still applies and will only be enhanced.

- Upon the completion of the Barangaroo South development, all the ground above the crown of the future metro tunnels under the slab spanning between the piles supporting Buildings R8 & R9 is retained. The minimum clearance from the underside of the slab to the crown of the future Sydney Metro tunnels will be 2m.

- The concrete segments are erected within the tail of the TBM shield. Pea gravel (followed later by high pressure grouting) or high pressure grouting alone from the within the tail shield of the TBM will fill the annulus formed between the surrounding ground the segmental lining. Grouting of the segments within or behind the tail shield of the TBM is an industry standard method of tunnel construction when using segments. Additional grouting of the ground can be preformed through cast in holes in the segments if required to fill potential voids formed above the tunnel.

- Transport NSW should ensure that when the tunnel is excavated under the building an additional level of tunnel construction surveillance is applied to that used outside the building foot print.

- The TBM can traverse beneath the load transfer slab above without the need for surface grouting during the tunneling works and therefore no penetrations in the slab or structural elements adjacent to the tunnel are required. In the case of a 1.8m thick slab and depending on the building use in the basement above this may be impractical to achieve anyway. Grouting of the ground surrounding the tunnel is in this case more efficiently carried out from within the tunnel. The integrity of the ground around the tunnel is required to be maintained to reduce lining deformation and tunnel lining flotation.

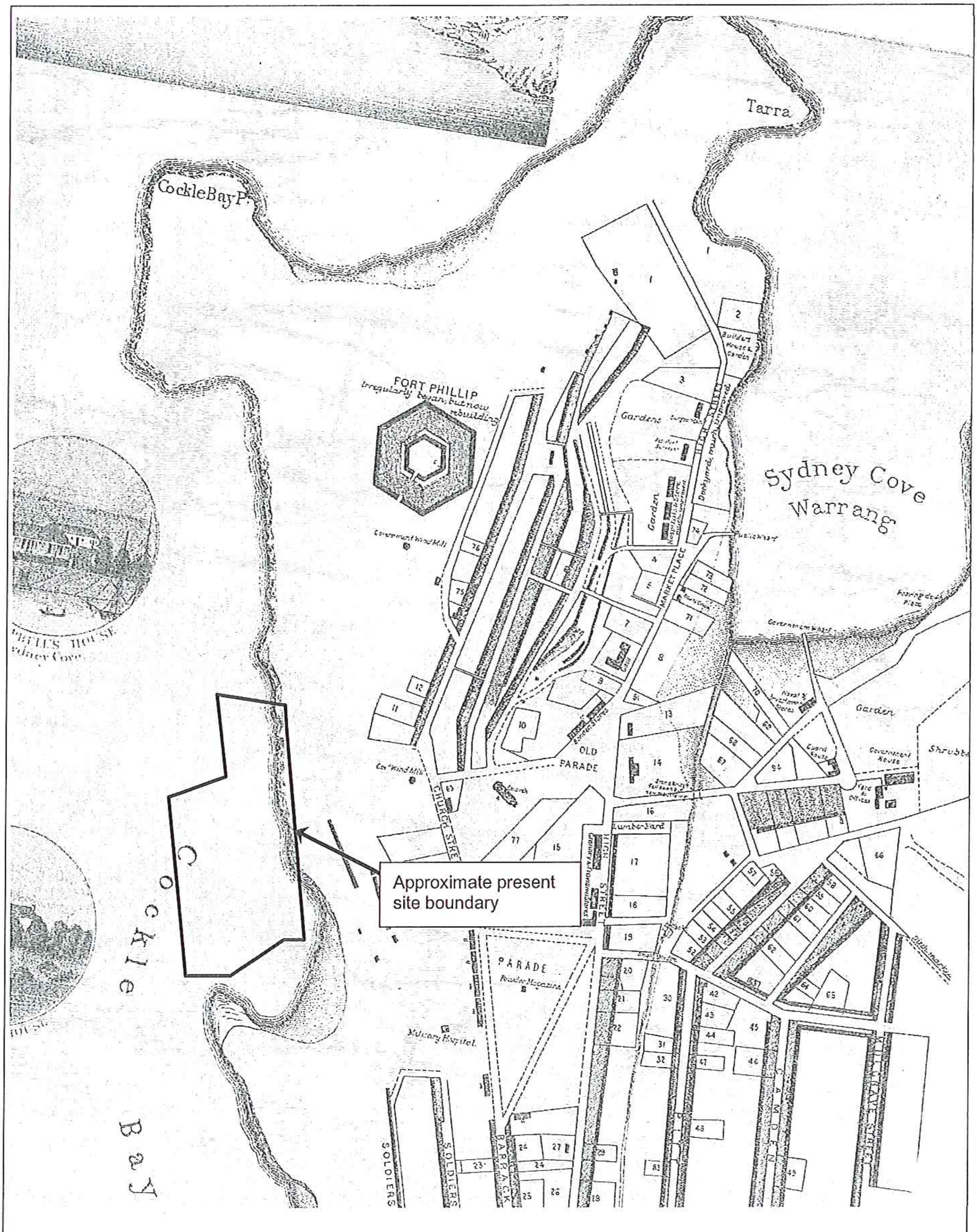
- The diaphragm wall (1200mm thick reinforced concrete) panels have been founded with approximately 3m of Class III or better sandstone cover between the tunnel crown and the toe of the diaphragm wall.

In addition to the above design and construct criteria, it will be important to ensure that the detailed designs and construction methodology are closely coordinated in an ongoing manner. Mott MacDonald therefore recommends that appropriate approvals regimes are established between Lend Lease and Sydney Metro.

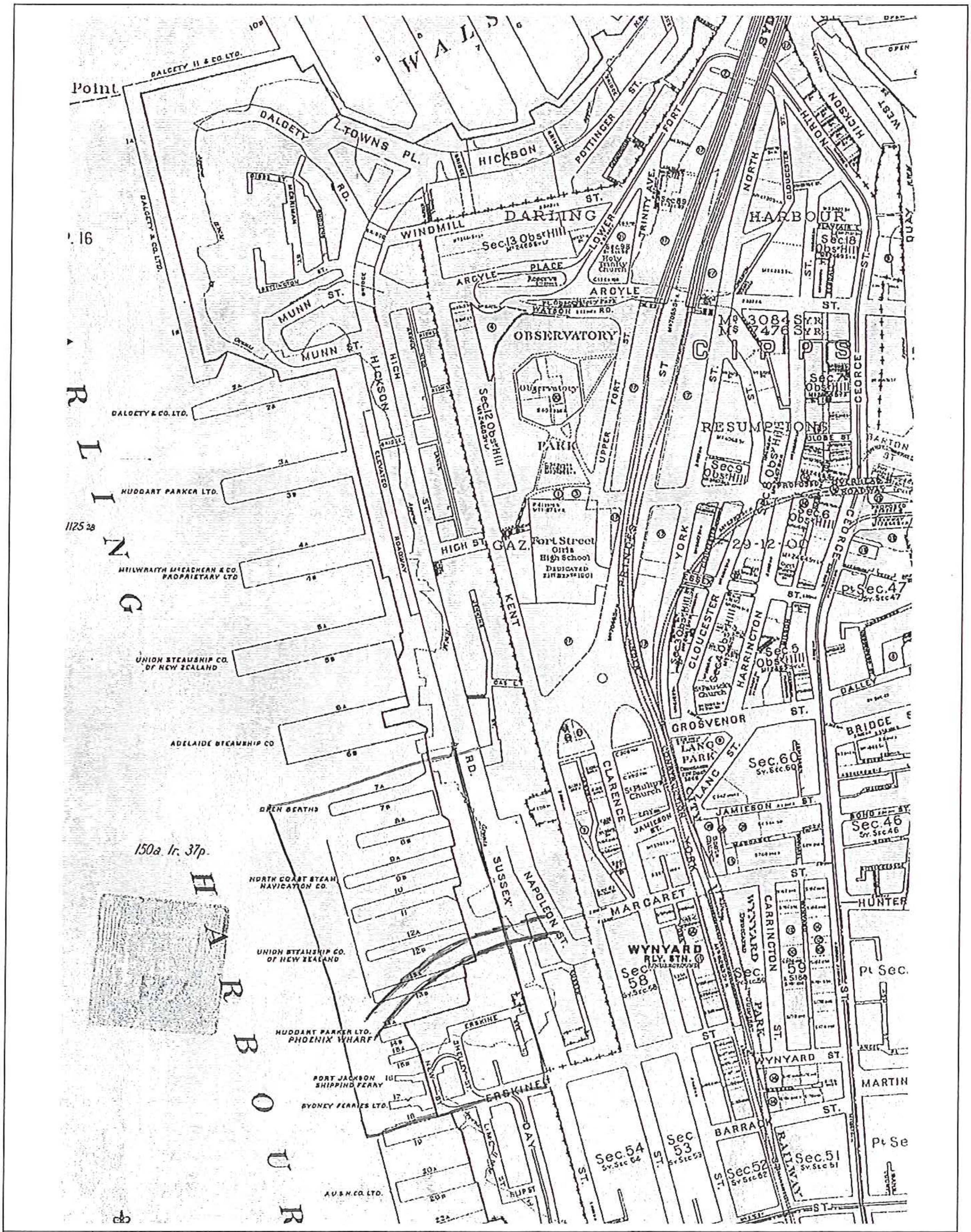
The preliminary design of the building is consistent with the design and construction principles agreed with NSW Transport and therefore detailed design of the building should be allowed to proceed on the basis of the conclusions, procedures and preliminary foundation structural drawings presented in this report.

Appendix A

Darling Harbour Historic Foreshore Plans, 1807 and 1930.



drawn	MF	coffey geotechnics SPECIALISTS MANAGING THE EARTH	client:	Bovis Lend Lease Pty Ltd
approved	RJB		project:	Barangaroo Development – Stage 1 Geotechnical Report
date	23/9/2010			
scale	NTS		title:	1807 Historic Map of Sydney
original size	A4		project no: GEOTLCOV24015AB	Figure 3



drawn	MF	coffey geotechnics SPECIALISTS MANAGING THE EARTH	client:	Bovis Lend Lease Pty Ltd
approved	RJB		project:	Barangaroo Development – Stage 1 Geotechnical Report
date	23/9/2010			
scale	NTS		title:	1930 Historic Map of Sydney Showing Finger Wharves
original size	A4		project no: GEOTLCOV24015AB	Figure 4

Appendix B

Section 1 - Metro Works Requirements (extract only) and Section 2 Construction Requirements (Extract only) as provided by Transport NSW

1 METRO WORKS REQUIREMENTS (Extract Only)

1.1 General

a) The Metro Works must be designed and constructed to enable the construction, operation and maintenance of the Metro Line 1 (Stage 1).

b) The Metro Works must provide for the support and preservation of existing infrastructure (including, but not limited to, roads, parks and other publicly accessible areas, footpaths and pedestrian facilities, bus, coach and taxi facilities and routes, bicycle routes, railways and light rail, Utility Services and buildings) except to the extent that the existing infrastructure needs to be adjusted or modified as a direct and unavoidable consequence of the PRI-1 Works.

c) The Metro Works must provide for future construction and developments of infrastructure adjacent to or above the Metro Works.

d) The design and construction of the Metro works must:

   i. minimise whole of life costs; and

   ii. include detailed risk assessments of all aspects of the proposed design and construction processes for the Running Tunnels and underground structures.

e) The PRI-1 Contractor must design and construct the Metro Works in accordance with the British Tunnelling Society and Institution of Civil Engineers - Specification for Tunnelling, 2nd Edition except:

   i. where the requirements of the SWTC or any part of the PRI-1 Contract specify a different standard or level of services, the requirements of the SWTC will prevail; and

   ii. where an Australian Standard exists that is equivalent to a British Standard specified in the British Tunnelling Society and Institution of Civil Engineers -Specification for Tunnelling 2nd Edition, then the equivalent Australian Standard will prevail.

1.2 Design Life

a) The Assets and Asset Components must have the following minimum Design Life (except as specified in Appendix 12):

i.	Running Tunnel elements including cast-in-situ concrete and sprayed concrete, segmented linings and cut and cover structures	100 years
ii.	tunnel portal and dive structures	100 years
iii.	turnout enlargements, crossover caverns, station shaft, pedestrian adit, pedestrian access stub connections, services adit and services shaft including cast-in-situ concrete and sprayed concrete	100 years
iv.	Barangaroo Pedestrian Link structures	100 years

v.	station cavern and box structures including cast-in-situ concrete and sprayed concrete and cut-and-cover structures	100 years
vi.	permanent ground anchors and rockbolts	100 years
vii.	other structural elements	100 years
viii.	drainage structures and inaccessible pipe systems	100 years
ix.	earthing and electrolysis protection	100 years
x.	road pavements	20 years
xi.	Temporary Works and Handover Works	10 years
xii.	Other Assets not detailed in numbers (i) to (xi) inclusive or in Appendix 12.	Typical industry values for similar Assets of a high standard and quality

1.3 Tunnel, Cavern, Shaft and Adit Requirements

1.3.1 Running Tunnels

a) The Running Tunnels must be provided at the locations shown on the drawings in Appendix 3 and the Running Tunnel centrelines must be within 100 mm of the tunnel centrelines that are defined in Appendix 3 as a series of straight lines between coordinates spaced at 1.00 m intervals.

b) The PRI-1 Contractor must ensure that the clear distance between the centrelines of the Running Tunnels and the tunnel concrete lining is no less than 2.85 m and no more than 2.95 m in all directions.

c) The Running Tunnels must have concrete linings that:

i. are permanent, durable and constructed using fibre reinforced concrete with a minimum thickness of 200mm;

ii. may be constructed with steel reinforcement (mesh and/or bar); and

iii. allow for fixing of overhead wire fittings, cables and other metro railway services and equipment using anchors with a maximum embedded depth of 125mm with no adverse impact on structural integrity or watertightness.

d) Where the Running Tunnel has been excavated by TBM techniques the tunnel lining must be fibre reinforced segmental precast concrete.

1.4 Concrete Finishes

Concrete finishes for formed surfaces must be Class 3 in accordance with AS 3610-1995 Formwork for concrete. Sprayed concrete must have a regular and even surface with a measured relative surface deviation from the sprayed surface within the range of -20mm/+20mm in any 3m length.

1.5 Waterproofing

a) For the tunnel portal and dive structure, the PRI-1 Contractor must provide:

i. a waterproof membrane over the roof slab, for the full extent of the tunnel portal and dive structure extending down to below the joint between the roof slab and walls. In addition, a protective layer must be provided over the waterproof membrane;

ii. a continuous waterproof joint between the wall and floor slabs, between adjacent floor slabs and between wall panels;

iii. a continuous waterproof joint at any construction joint between the wall and roof slabs and between adjacent roof slabs; and

iv. appropriate subsoil drainage to minimise the presence of water adjacent to the membrane.

b) For Running Tunnels, station caverns, shafts and adits constructed by roadheader techniques that incorporate permanent concrete linings the PRI-1 Contractor must provide:

i. a waterproof membrane and drainage layer in accordance with the British Tunnelling Society and Institution of Civil Engineers - Specification for Tunnelling, 2nd Edition installed in accordance with the manufacturer's specifications;

ii. a waterproof membrane and drainage layer that is self-extinguishing;

iii. evidence obtained from the manufacturer that no components of the membrane will leach out and deleteriously affect durability of any of the following:

A. the waterproofing membrane;

B. the drainage/protective layer; and

C. other plastic materials or PVC materials; and

iv. protection to the waterproof membrane using a protective layer over the waterproofing membrane.

c) For Running Tunnels constructed by TBM techniques the PRI-1 Contractor must provide a water sealing system in accordance with the British Tunnelling Society and Institution of Civil Engineers - Specification for Tunnelling, 2nd Edition.

1.6 Watertightness

a) The Metro Works must achieve the following watertightness grades:

i.	Running Tunnels	Watertightness	Grade A
ii.	tunnel portal and dive structure	Watertightness	Grade A
iii.	turnout enlargements and crossover caverns	Watertightness	Grade A
iv.	station caverns	Watertightness	Grade A
v.	station shafts	Watertightness	Grade C
vi.	pedestrian adits, pedestrian access stub connections, services adits and services shafts	Watertightness	Grade A

vii.	station box structures at White Bay and Barangaroo-Wynyard	Watertightness	Grade A
viii.	Barangaroo Pedestrian Link	Watertightness	Grade A
ix.	cross passages	Watertightness	Grade A
x.	niches and enlargements	Watertightness	Grade A
xi.	sumps	Watertightness	Grade B

b) The watertightness grades referred to above are defined by the acceptable indications of water on the internal structure surface as follows:

i. Watertightness Grade A: substantially watertight with water indications limited to minor damp patches on the faces of interior surfaces of concrete and/or sprayed concrete elements with no visible flow of water.

ii. Watertightness Grade B: water indications limited to damp patches on the faces of interior surfaces of concrete and/or sprayed concrete elements with minor weeping.

iii. Watertightness Grade C: water indications limited to minor wet patches on excavated surfaces with visible flow of water at joints and imperfections within the excavated surface only.

1.7 Groundwater Seepage

a) The PRI-1 Contractor must ensure that there are no adverse impacts from groundwater chemistry on the structural integrity of the Metro Works structures and groundwater collection and drainage system.

b) Without limiting the requirements in relation to groundwater control and waterproofing for Drained structures, groundwater seepage and ingress at the relevant Date of Construction Completion and thereafter must not exceed the following:

i. gross seepage rate must not exceed 6.5 litres per day per m^2 of excavated surface;

ii. groundwater ingress through the permanent structural concrete lining must not exceed 0.1 litres per day per m^2 of lining surface; and

iii. groundwater ingress through the permanent structural concrete lining must not exceed 0.1 litres per day per m^2 of lining surface for any 10 m length of lining.

c) Without limiting the requirements in relation to groundwater control and waterproofing for Undrained structures, groundwater ingress through the permanent structural concrete lining at the relevant Date of Construction Completion and thereafter must not exceed:

i. 0.1 litres per day per m^2 of lining surface; and

ii. 0.1 litres per day per m^2 of lining surface for any 10m length of lining.

d) Without limiting the requirements in relation to groundwater control for station shafts, groundwater seepage and ingress at the relevant Date of Construction Completion and thereafter must not exceed a gross seepage rate of 2.5 litres per day per m^2 of excavated surface.

1.8 Groundwater Control

a) The Metro Works must be designed as Drained or Undrained as follows:

i.	Running Tunnels	Undrained
ii.	tunnel portal and dive structure including sump	Undrained
iii.	turnout enlargements and crossover caverns	Undrained
iv.	station caverns	Drained
v.	station shafts	Drained
vi.	pedestrian adits, pedestrian access stub connections, services adits and services shafts	Drained
vii.	station box structures at White Bay and Barangaroo-Wynyard	Undrained
viii.	Barangaroo Pedestrian Link including sump	Drained
ix.	cross passages	Undrained
x.	niches and enlargements	Undrained
xi.	sumps at station caverns and station shafts	Drained
xii.	sumps at station boxes	Undrained

b) The structural design of the Metro Works must comprehensively accommodate hydrostatic pressures including those resulting from any blockage to the groundwater collection and drainage system without adverse impacts on the Metro Works.

c) Lowering of groundwater levels using permanent dewatering system pumping is not permitted.

d) The PR1-1 Contractor must provide a groundwater collection and drainage system that can be easily maintained and flushed to remove any blockages including those caused by iron bacteria sludge. . The PRI-1 Contractor must also provide separate groundwater treatment systems at the station caverns, station shafts and the pedestrian link at Barangaroo-Wynyard. The groundwater collection and drainage system and the groundwater treatment system must allow all groundwater seepage associated with the Metro Works designed as Drained structures to be captured, treated and disposed of in accordance with the Environmental Documents and the requirements of relevant Authorities.

e) The PRI-1 Contractor must provide a groundwater collection system to allow all groundwater seepage associated with the Metro Works designed as Undrained structures to be captured and transferred to the treatment systems at the station caverns, station shafts and the pedestrian link at Barangaroo-Wynyard for treatment and disposal in accordance with the Environmental Documents and the requirements of relevant Authorities. The standing level of groundwater seepage in the Metro Works designed as Undrained structures must not exceed a depth of 25 mm.

2 CONSTRUCTION REQUIREMENTS (Extract Only)

2.1 Work Methods and Training

a) The methods of tunnelling and excavation, working at heights, protection from falling objects and other construction activities must conform to the requirements of relevant Authorities, including WorkCover NSW.

b) The PRI–1 Contractor must provide its personnel, and its Subcontractors' personnel with training in the construction techniques and work methods to be applied during the performance of the PRI-1 Contractor's Activities, including work methods for tunnelling and excavation.

2.2 Safety

a) The PRI-1 Contractor must carry out a safety risk assessment in respect of all construction activities. The safety risk assessment must include the following as a minimum:

   i. identification, description and, where possible, quantification of foreseeable risks;

   ii. assessments of the rate at which hazardous conditions may develop;

   iii. appropriate procedures and contingency plans which are capable of securing the safety of workers, the public, the Project Works, the Temporary Works and adjacent properties within the time necessary to prevent hazardous conditions from occuring or worsening.

b) The PRI-1 Contractor must ensure that all excavations are maintained in a stable condition and are secured against public and any unauthorised access at all times.

c) The PRI-1 Contractor must take all measures necessary to comply with the procedures and contingency plans referred to in paragraph (a)iii. in this subsection.

2.3 Quality of Material and Workmanship

All materials and workmanship must be of the quality necessary to meet the requirements of the PRI-1 Contract.

2.4 Tunnelling and Excavation

a) TBMs must include the ability to drill probe holes ahead of the face of the tunnel drive in order to determine the likely nature and water-bearing characteristics of the materials ahead of the excavation. Operations in tunnel drives and within excavations must be suspended or modified as may be necessary to permit the drilling of the probe holes and testing for the presence of methane and hydrocarbons.

b) The finished excavation profile for underground works using explosives must be formed by using perimeter-blasting techniques.

c) Excavation and installation of ground support must be carried out with such care and strict precautions necessary so as to minimise ground movement or subsidence and prevent damage to adjacent property, and to ensure that the excavated surfaces exposed are stable and that overbreak is minimised. All excavated surfaces must be regularly examined and loose material removed or otherwise made safe. The excavations must be promptly and safely supported at all times.

d) Excavation and installation of ground support must utilise machines and methods of working such that no personnel are required to be beneath unsupported ground.

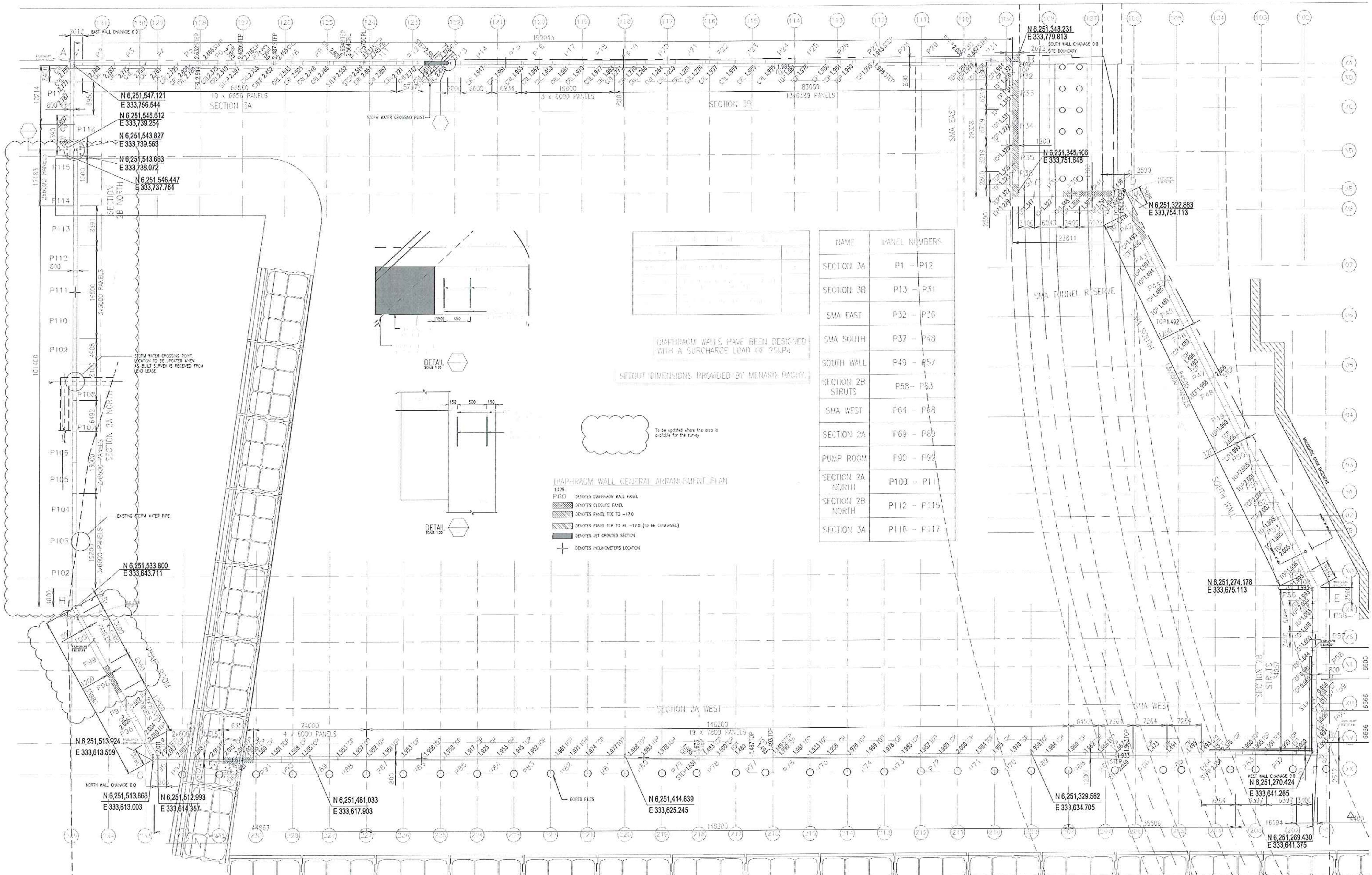
e) Mapping of all installed support, including all rockbolts, steel sets, forward reinforcement and sprayed concrete thicknesses, must be undertaken by an experienced surveyor or tunnel engineer. The PRI-1 Contractor must compile and submit all mapping records to the Principal's Representative in accordance with the requirements set out in Appendix 23.

f) Where segmental precast concrete linings are used, the PRI-1 Contractor must ensure that manufacture of the segmental precast concrete linings is carried out within a suitable facility for the production of high quality precast concrete elements. The PRI-1 Contractor must ensure that the segment manufacturer is certified to AS/NZS ISO 9001:2008 Quality management systems - Requirements. The control of production procedures must be undertaken by experienced specialist personnel familiar with the manufacture of high strength, durable, dimensionally accurate precast concrete elements.

g) For sections of excavations constructed by roadheader techniques that incorporate structural concrete linings, the PRI-1 Contractor must provide a supervisor experienced in the installation of waterproof membranes in excavations constructed by roadheader technique. The supervisor must be appropriately trained and experienced in the installation of waterproof membranes of similar scope and method.

Appendix C

R8 & R9 Buildings Structural Foundation Preliminary Design Drawings



NAME	PANEL NUMBERS
SECTION 3A	P1 – P12
SECTION 3B	P13 – P31
SMA EAST	P32 – P36
SMA SOUTH	P37 – P48
SOUTH WALL	P49 – P57
SECTION 2B STRUTS	P58 – P63
SMA WEST	P64 – P68
SECTION 2A	P69 – P89
PUMP ROOM	P90 – P99
SECTION 2A NORTH	P100 – P111
SECTION 2B NORTH	P112 – P115
SECTION 3A	P116 – P117

Key Plan

Rev.	Item	Revision Description	Date
L		RL'S TOP OF WALLS ADDED	18.10.12
K		LEND LEASE REVIEW	18.04.12
J		GRID "XX" AMENDED	05.04.12
I		SETOUT FOR PANELS, SMA WEST & INCLINOMETERS REVISED AND STRUT STEELWORK ADDED	25.01.12
H		SETOUT FOR PANELS P13 - P15 REVISED	06.01.12
G		COUPLERS & DETAILS ADDED	15.12.11
F		NORTH D-WALL SETOUT REVISED	02.12.11
E		EXISTING STORM WATER PIPE LOCATION REVISED	07.11.11
D		SETOUT FOR PANELS P13-P36, P113 & P114 REVISED	28.10.11
C		LEND LEASE REVIEW	20.10.11
B		LEND LEASE REVIEW	18.10.11
A		LEND LEASE REVIEW	10.10.11

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MENARD BACHY REVIEW BY: MALCOLM WAKEFIELD - 18.04.12

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Project

BARANGAROO SOUTH

Title

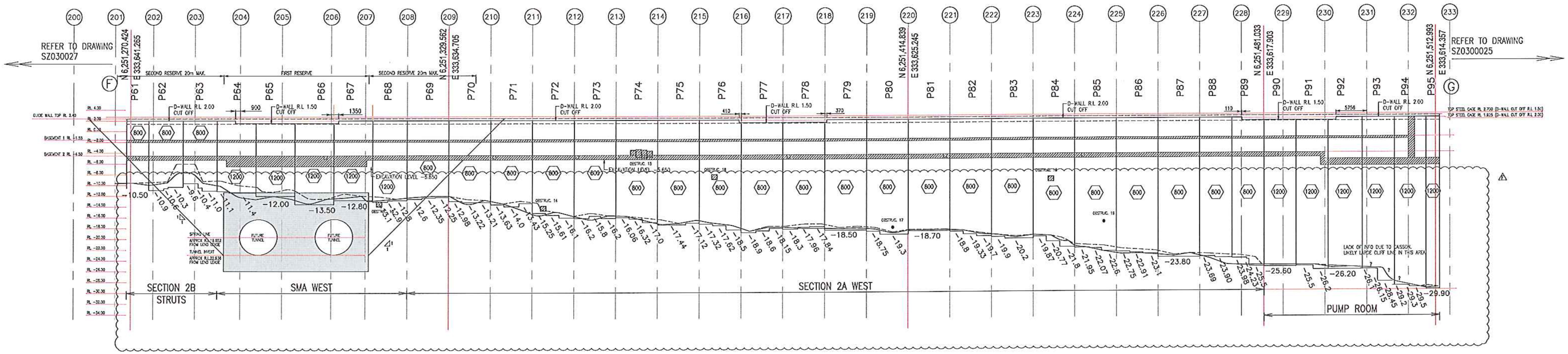
DIAPHRAGM GENERAL ARRANGEMENT PLAN

Drawn By	Date	Purpose	Checked By	Date	Approved By	Date
M.B.	18.10.12	REVIEW	G.ISEPPI	18.10.12	P.DAVIS	18.10.12

SCALE 1:250

Project No.	Site No.	Drawing No.	Revision
161136	BB1	SZ0300011	L

A0



WEST DIAPHRAGM ELEVATION

- DENOTES VOID OBSTRUCTION
- DENOTES CONCRETE OR OTHER UNKNOWN MATERIAL OBSTRUCTION
- DENOTES INFERRED CLASS IV ROCK (AHD)
- DENOTES INFERRED CLASS III ROCK (AHD)
- 800 PANEL THICKNESS
- −12.40 DENOTES PRELIMINARY PANEL TOE LEVEL (TO BE CONFIRMED DURING CONSTRUCTION AND SATISFIES THE SOCKET CRITERIA).
- DENOTES SMA PROTECTION ZONE
- XC DENOTES LEND LEASE GRID SYSTEM

EXCAVATION LEVELS SUBJECT TO REVIEW

SOCKET CRITERIA	
PANEL NUMBERS	COMMENTS
P61–P63	MINIMUM 1000 IN CLASS IV ROCK OR BETTER.
P64	MINIMUM 1400 IN CLASS IV ROCK OR BETTER.
P65–P66	MINIMUM 1000 IN CLASS IV ROCK OR BETTER.
P67	MINIMUM 800 IN CLASS IV ROCK OR BETTER.
P68–P95	MINIMUM 200 IN CLASS III ROCK OR 500 IN CLASS IV ROCK.

DIAPHRAGM WALL TOE LEVEL TO COMPLY WITH SOCKET CRITERIA. ACTUAL TOE LEVEL TO BE DETERMINED DURING EXCAVATION. STEPPED/FLAT PANEL TOES SUBJECT TO VARIATION BASED ON ENCOUNTERED GEOLOGY.

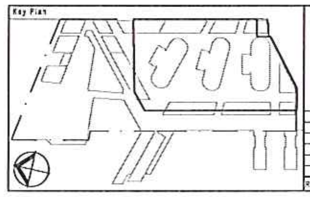
CLIENT INPUT DRAWING SCHEDULE		
DRAWING NUMBER	DRAWING NAME	REVISION
SD1004003	BULK EXCAVATION WALL ELEVATIONS SHEET 3	01
SD1004004	BULK EXCAVATION WALL ELEVATIONS SHEET 4	01
SD1004005	BULK EXCAVATION WALL ELEVATIONS SHEET 5	01

NOTE: 1. GRADE III AND IV SANDSTONE ROCK LEVELS INFERRED FROM MENARD BACHY IN BARANGAROO STAGE 0 SITE INVESTIGATIONS REPORT (REF: 5020145-Q-ABV-0305-R-00).

2. POSITION AND LEVEL FOR FUTURE TUNNELS ARE EXTRACTED FROM SD1000011.

SETOUT DIMENSIONS PROVIDED BY MENARD BACHY.

Key Plan



Rev.	Item	Revision Description	Date
F		TOE LEVELS AMENDED	15.03.12
E		TOE LEVELS ADDED	23.12.11
D		TOE LEVELS ADDED	02.12.11
C		REVISED ACCORDING TO LEND LEASE INFO	30.11.11
B		LEND LEASE REVIEW	18.11.11
A		LEND LEASE REVIEW	18.10.11

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MENARD BACHY REVIEW BY: Malcolm Wakefield 15.03.12

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ACN 113 466 514

PDR Job Number: 20101330

PDR APPROVED FOR STRUCTURAL: Paul Davis 15.03.12

Principal

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Developer	Lend Lease
Project Management & Construction	Lend Lease
Design	Lend Lease

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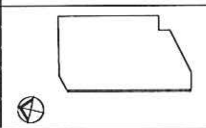
Project

BARANGAROO SOUTH



Title

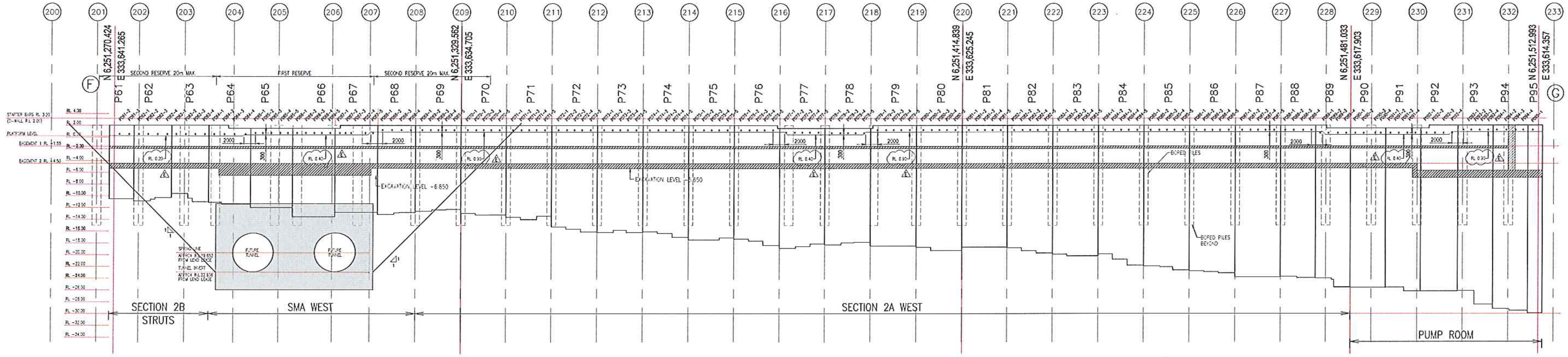
WEST ELEVATION - SHEET 1

Drawn By	Date	Purpose	Checked By	Date	Approved By	Date
M.B.	15.03.12	REVIEW	G. ISEPPI	15.03.12	P.DAVIS	15.03.12

SCALE 1:250

Project No.	Site No.	Drawing No.	Revision
161136	BB1	SZ0300021	F

A0



WEST DIAPHRAGM ELEVATION

EXCAVATION LEVELS SUBJECT TO REVIEW

NOTE: WHERE ANCHOR R.L. CHANGES THE PLATFORM LEVEL CAN BE RELOCATED TO THE LOWER ANCHOR LEVEL ONCE THE ADJACENT HIGHER ANCHORS HAVE BEEN STRESSED.

SOCKET CRITERIA	
PANEL NUMBERS	COMMENTS
P61–P63	MINIMUM 1000 IN CLASS IV ROCK OR BETTER.
P64	MINIMUM 1400 IN CLASS IV ROCK OR BETTER.
P65–P66	MINIMUM 1000 IN CLASS IV ROCK OR BETTER.
P67	MINIMUM 800 IN CLASS IV ROCK OR BETTER.
P68–P95	MINIMUM 200 IN CLASS III ROCK OR 500 IN CLASS IV ROCK.

DIAPHRAGM WALL TOE LEVEL TO COMPLY WITH SOCKET CRITERIA. ACTUAL TOE LEVEL TO BE DETERMINED DURING EXCAVATION. STEPPED/FLAT PANEL TOES SUBJECT TO VARIATION BASED ON ENCOUNTERED GEOLOGY.

CLIENT INPUT DRAWING SCHEDULE		
DRAWING NUMBER	DRAWING NAME	REVISION
SD1004003	BULK EXCAVATION WALL ELEVATIONS SHEET 3	01
SD1004004	BULK EXCAVATION WALL ELEVATIONS SHEET 4	01
SD1004005	BULK EXCAVATION WALL ELEVATIONS SHEET 5	01

NOTE: 1. GRADE III AND IV SANDSTONE ROCK LEVELS INFERRED FROM MENARD BACHY IN BARANGAROO STAGE 0 SITE INVESTIGATIONS REPORT (REF: 5020146-Q-ASV-0305-R-00).

2. POSITION AND LEVEL FOR FUTURE TUNNELS ARE EXTRACTED FROM SD1000011.

SETOUT DIMENSIONS PROVIDED BY MENARD BACHY.

WORK IN PROGRESS

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MENARD BACHY
MENARD BACHY REVIEW BY: Malcolm Wakefield 18.05.12

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ACN 113 488 514
PDR Job Number 2010130
PDR APPROVED FOR STRUCTURAL: Paul Davis 18.05.12

Principal: Lend Lease

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Project: BARANGAROO SOUTH

Title: WEST ELEVATION - SHEET 2

Drawn By	Date	Purpose	Checked By	Date	Approved By	Date
MB	18.05.12	REVIEW	G. ISEPPI	18.05.12	P.DAVIS	18.05.12

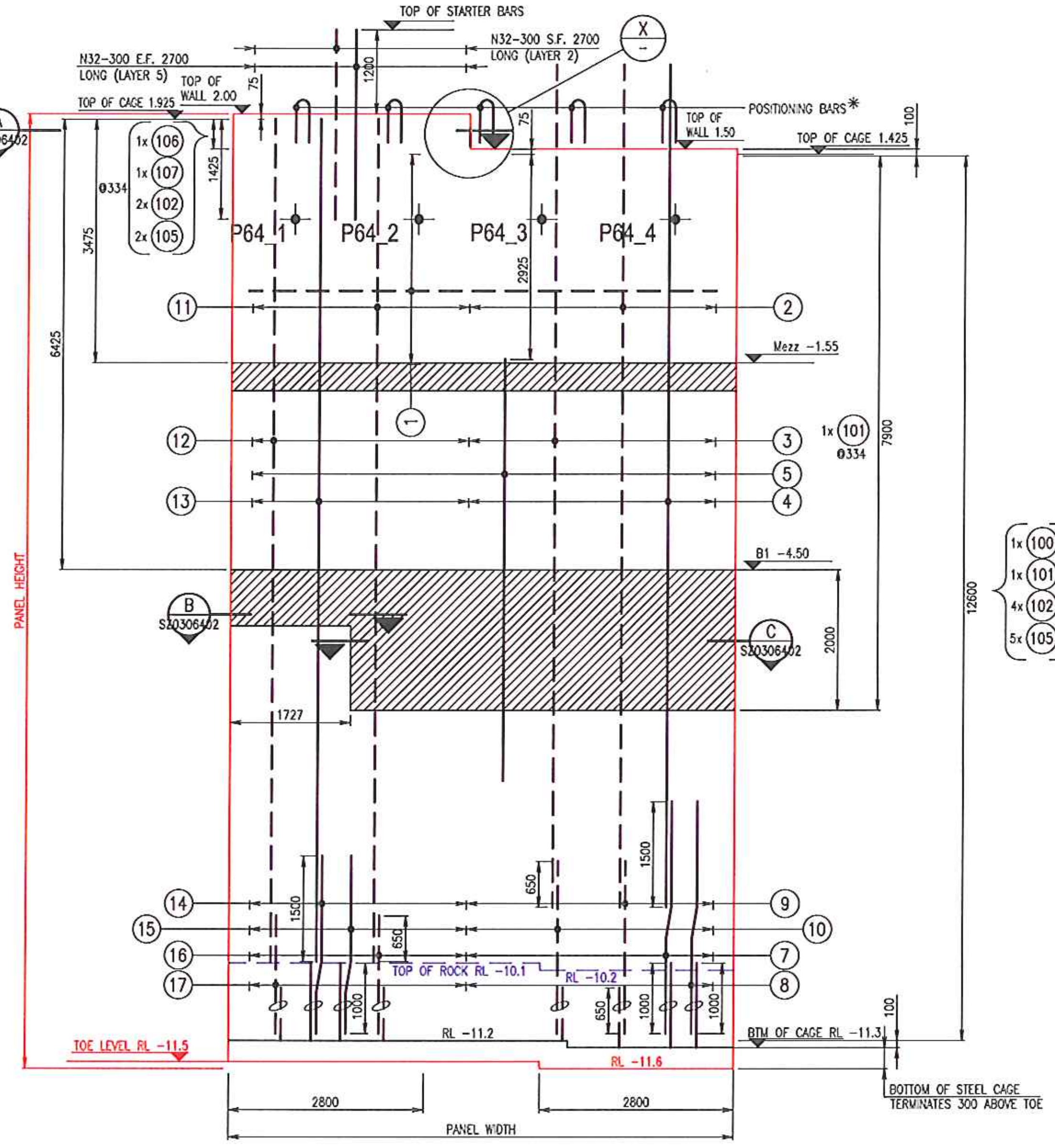
SCALE 1:250

Project No	Site No	Drawing No	Revision
161136	BB1	SZ0300022	E

A0

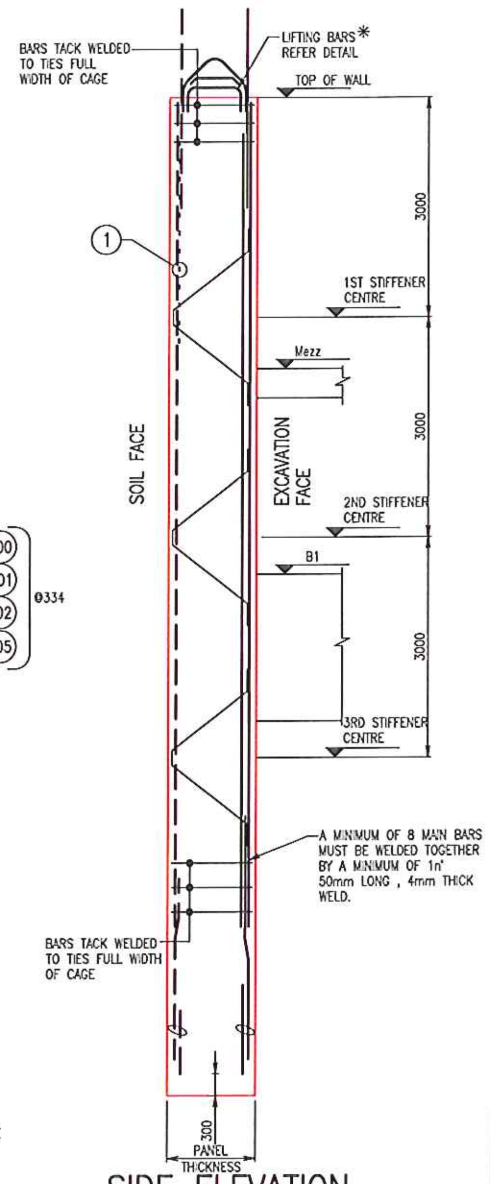
PANEL 64					
PANEL SIZE	DESIGN	AS CONSTRUCTED	PANEL SIZE	DESIGN	AS CONSTRUCTED
CAGE HEIGHT	13,075/ 12,525	13125/12625 /12725	THICKNESS	1,200	1,200
CAGE WIDTH	6,564/ 2,863	6,564/ 2,863	REO. CAGE MASS	12.1t	12.3t

BAR MARK	BAR SIZE	CHECK	No. OF	CHECK	SPACING	CHECK	LENGTH/WIDTH	CHECK
1	N36		24 IN 12 PAIRS		250		6564	
2	N24		13		161		12,000	
3	N20		9		161		12,000	
4	N40		22		161		12,000	
5	N36		7		161		6,000	
6	N/A		N/A		N/A		N/A	
7	N24		13		161		3,300	
8	N20		9		161		3,300	
9	N24		13		161		2,450	
10	N20		9		161		2,450	
11	N24		11		161		12,000	
12	N20		8		161		12,000	
13	N40		19		161		12,000	
14	N24		11		161		2,525	
15	N20		8		161		2,525	
16	N24		11		161		1,675	
17	N20		8		161		1,675	
100	N16		39		334		8,628	
101	N16		63		334		7,552	
102	N12		160		334		2,793	
103	N/A		N/A		N/A		N/A	
104	N/A		N/A		N/A		N/A	
105	N16		199		334		1,212	
106	N16		2		334		4,127	
107	N16		2		334		3,051	



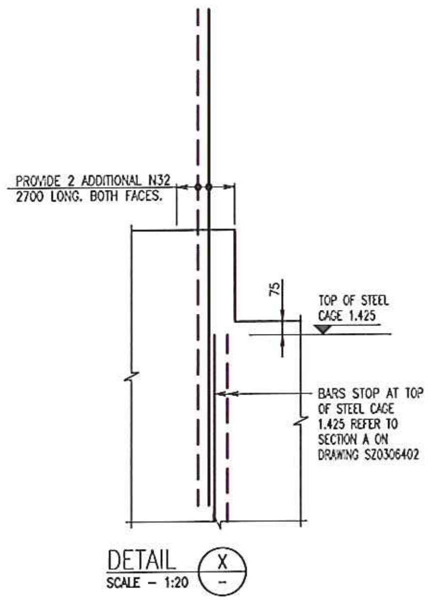
PANEL ELEVATION

SCALE 1:50



SIDE ELEVATION

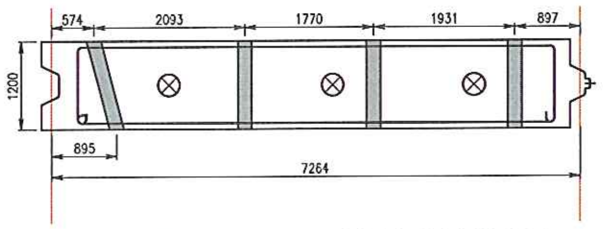
SCALE 1:50



DETAIL X

SCALE - 1:20

CAGE BUILT TO SUIT TOE LEVEL OF RL -11.40 AND THEN EXTENDED TO SUIT STEPPED TOE LEVEL OF RL -11.50 & RL -11.60



PANEL P64 - KEY DIAGRAM

THOROUGH VISUAL CHECK OF ALL CAGES WILL BE MADE UPON ARRIVAL ON SITE.

ALL HORIZONTAL STEEL WILL BE TIED TO THE MAIN BARS (EVERY THREE MAIN BARS) WITH DOUBLE TYING WIRE.

ALL LIFTING AND POSITIONING BARS WILL BE MADE OF MILD STEEL OF MINIMUM YIELD STRENGTH: 235MPA IF IN DOUBT WITH THE LIFTING PROCEDURE, PLEASE CONTACT THE DESIGN ENGINEER.

ALL MAIN BARS SUPPORTING A LIFTING OR POSITIONING BAR WILL BE WELDED TO THE TOP 8 HORIZONTAL FRAMES.

* INDICATES REINFORCEMENT MARKED IS FOR ERECTION AND LIFTING AND IS NOT PART OF THE STRUCTURAL CAGE. POSITIONING BARS TO BE DETERMINED ON SITE.

LEVELS SHOWN ARE RELATIVE TO AUSTRALIAN DATUM mAHD.

ANCHOR INCLINATION	
ANCHOR	ANGLE
P64_1	40°
P64_2	45°
P64_3	45°
P64_4	45°

REFER TO DRAWING SZ0306402 FOR SECTIONS.
REFER TO DRAWING SZ0300052 FOR DETAILS

CONCRETE NOTES

MINIMUM CONCRETE STRENGTH AT 28 DAYS

LOCATION	F'c
ALL ELEMENTS	50 MPa

COVER TO REINFORCEMENT

LOCATION	COVER
ALL ELEMENTS	75mm Min.

AS BUILT

Rev.	Revision Description	Date
F	AS BUILT	29.06.12
E	LEND LEASE REVIEW	09.06.12
D	ISSUED FOR CONSTRUCTION	31.01.12
C	LEND LEASE REVIEW	25.01.12
B	LEND LEASE REVIEW	14.12.11
A	LEND LEASE REVIEW	15.11.11

Contractors: Menard Bachy, Level 3, 13-15 Lyonpark Road, Macquarie Park NSW 2113, +61 2 9491 7100 — menard BACHY

MENARD BACHY REVIEW BY: Malcolm Wakefield 29.06.12

Designers: Coffey Geotechnics Pty. Ltd. 8/12 Mars Road Lane Cove West NSW 2066, Ph: +61 2 9911 1000 — coffey geotechnics

In association with: Paul Davis Rajalingam Smart Structures, Ground Floor, 55 Chandos St, St Leonards NSW 2065, Ph: +61 2 9004 6955 — paul davis rajalingam SMART STRUCTURES

FOR APPROVED FOR STRUCTURAL: Paul Davis 29.06.12

Principal: Lend Lease — Developer: Lend Lease; Project Management & Construction: Lend Lease; Design: Lend Lease

Project: BARANGAROO SOUTH

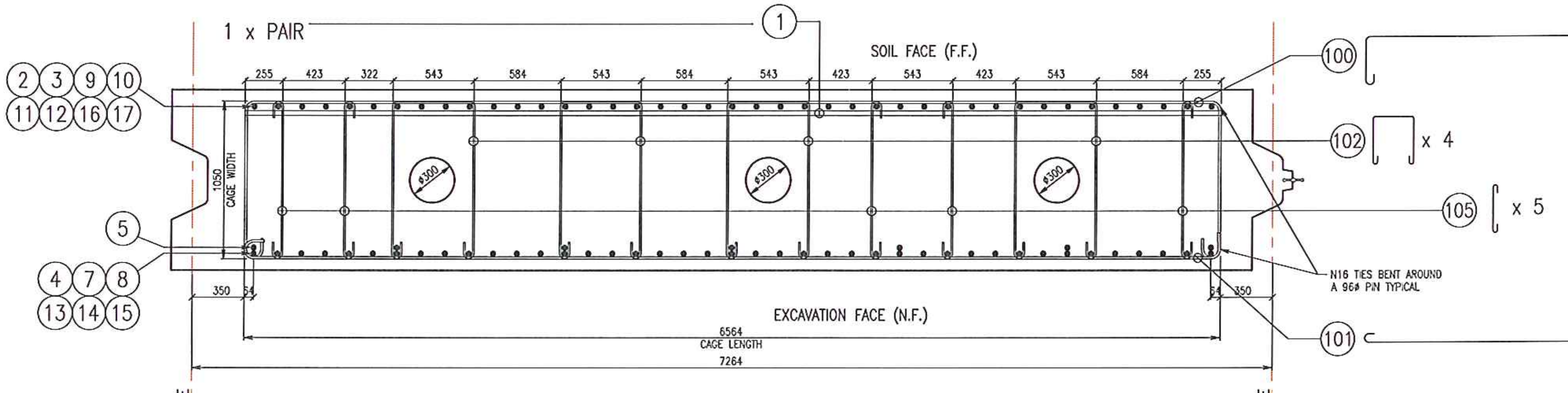
Title: SHOP DRAWING FOR D-WALL PANEL SMA WEST (P64 TO P68) ELEVATION - PANEL P64

Drawn By: RCL 29.06.12 — Checked By: G.ISEPPI 29.06.12 — Approved By: P.DAVIS 29.06.12

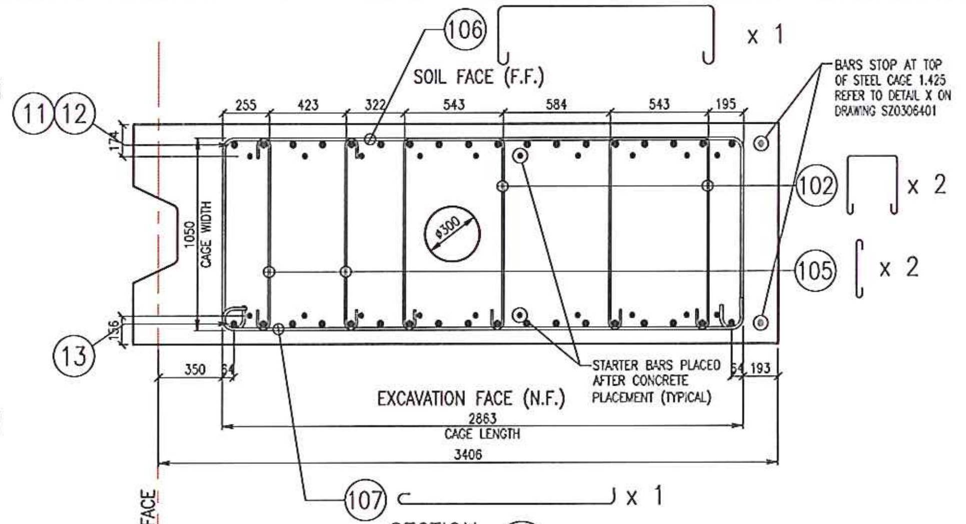
SCALE 1:50

Project No. 161136 — Site No. BB1 — Drawing No. SZ0306401 — Revision F

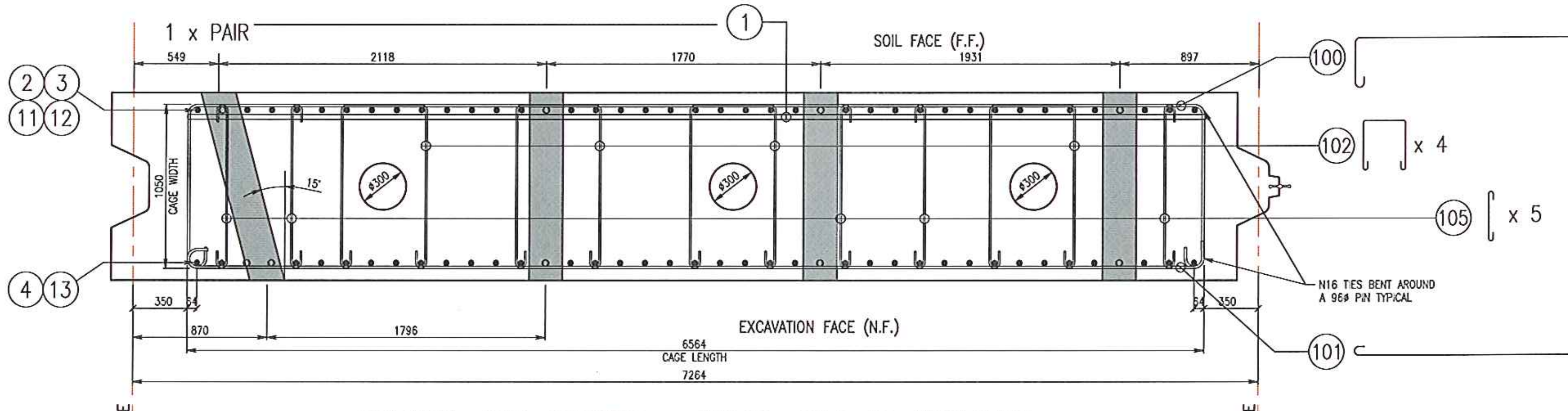
A1



TYPICAL BAR SETOUT – PANEL P64
SCALE 1:20



SECTION A
SCALE – 1:20 SZ0306401



TYPICAL BAR SETOUT – PANEL P64 AT ANCHORS
SCALE 1:20

CONCRETE NOTES

MINIMUM CONCRETE STRENGTH AT 28 DAYS

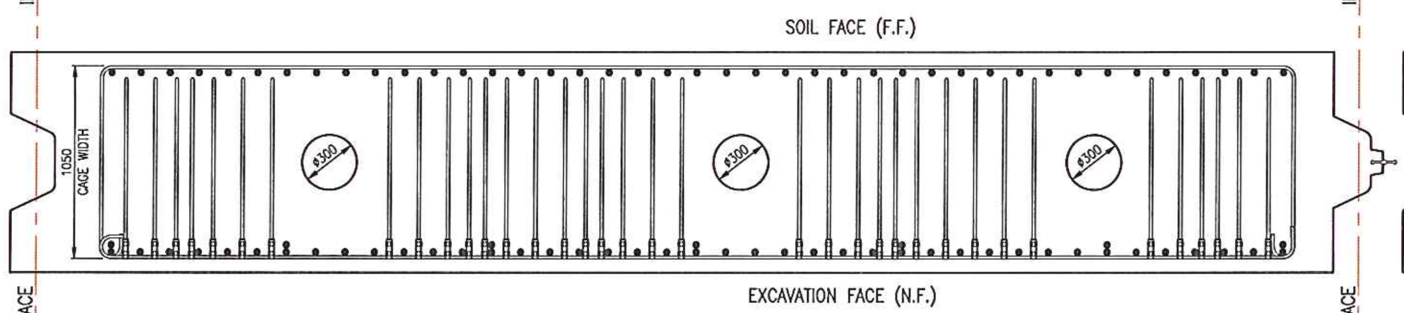
LOCATION	F'c
ALL ELEMENTS	50 MPa

COVER TO REINFORCING

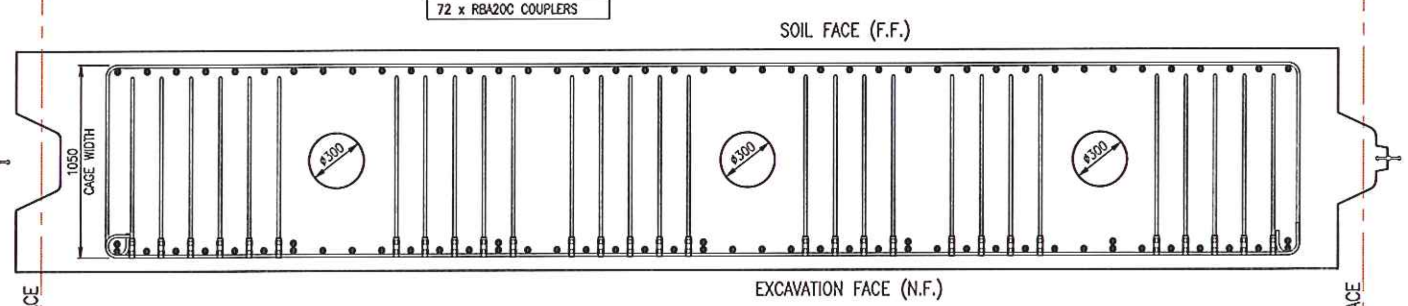
LOCATION	COVER
ALL ELEMENTS	75mm Min.

NOTE: SUSPENSION AND LATERAL REINFORCEMENT IS FOR ERECTION AND LIFTING AND IS NOT PART OF THE STRUCTURAL CAGE.

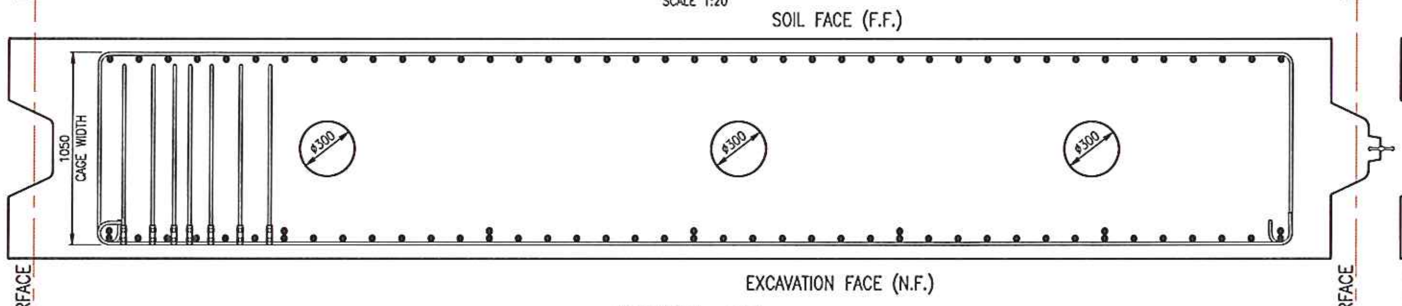
COUPLER SCHEDULE
BASEMENT
80 x RB32C COUPLERS
MEZZANINE
72 x RBA20C COUPLERS



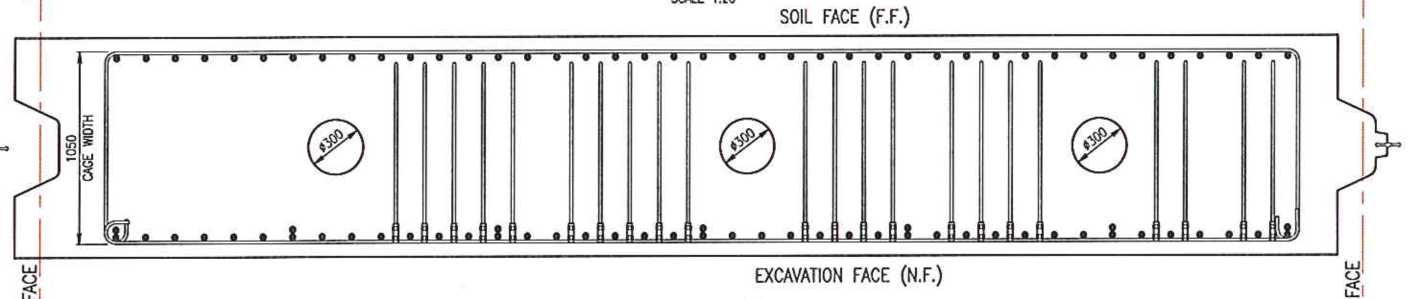
MEZZANINE COUPLER SETOUT
SCALE 1:20



BASEMENT 1 COUPLER SETOUT – TOP LAYER
SCALE 1:20



SECTION B
SCALE – 1:20 SZ0306401



SECTION C
SCALE – 1:20 SZ0306401

AS BUILT

Key Plan

Rev.	Item	Revision Description	Date
D		AS BUILT	29.06.12
C		ISSUED FOR CONSTRUCTION	31.01.12
B		LEND LEASE REVIEW	25.01.12
A		LEND LEASE REVIEW	14.12.11

Contractors:
Menard Bachy
Level 3
13-15 Lyonpark Road
Macquarie Park NSW 2113
+61 2 9491 7100
MENARD BACHY
MENARD BACHY REVIEW BY : Malcolm Wakefield 29.06.12

Designers:
Coffey Geotechnics Pty. Ltd.
8/12 Mars Road
Lane Cove West NSW 2066
Ph: +61 2 9911 1000
coffey geotechnics

In association with:
Paul Davis Rajalingam
Smart Structures
Ground Floor
55 Chandos St
St Leonards NSW 2065
Ph: +61 2 9004 8855
paul davis rajalingam SMART STRUCTURES ACN 113 468 614
PDR Job Number: 2010130
PDR APPROVED FOR STRUCTURAL : Paul Davis 29.06.12

Principal: Lend Lease

Developer	Lend Lease
Project Management & Construction	Lend Lease
Design	Lend Lease

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Project: BARANGAROO SOUTH.

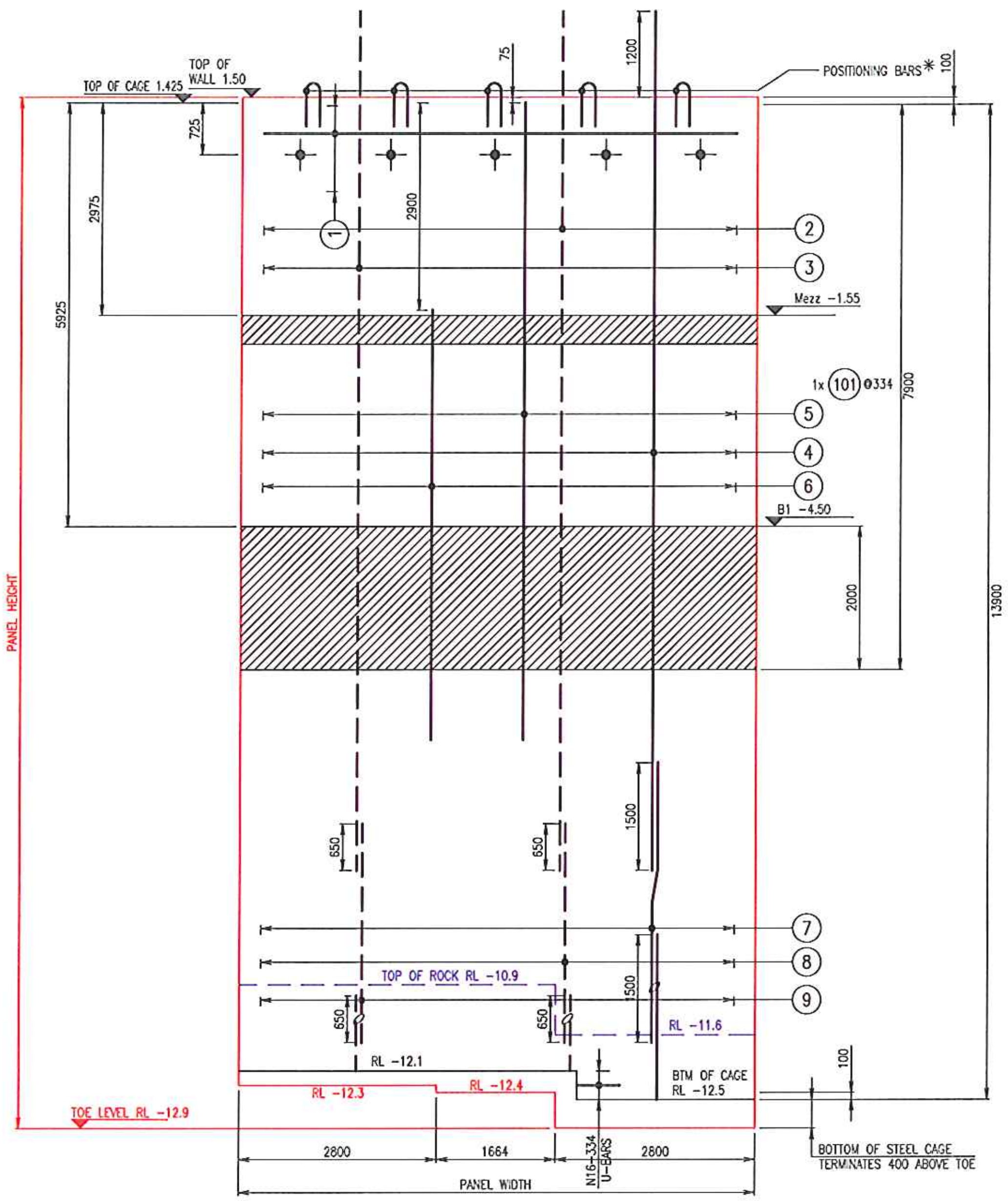
Title: SHOP DRAWING FOR D-WALL PANEL SMA WEST (P64 TO P68) DETAILS - PANEL P64

Drawn By	Date	Purpose	Checked By	Date	Approved By	Date
R.C.L.	29.06.12	As Built	G. ISEPPI	29.06.12	P. DAVIS	29.06.12

SCALE 1:20

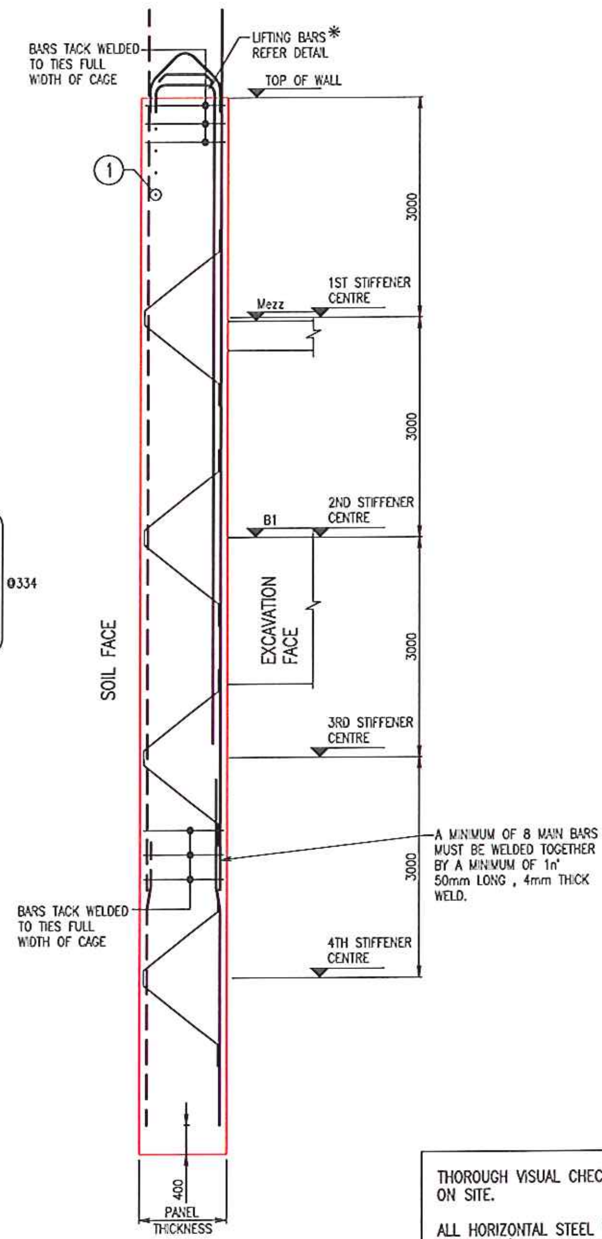
Project No.	Site No.	Drawing No.	Revision
161136	BB1	SZ0306402	D

A1



PANEL ELEVATION

SCALE 1:50



SIDE ELEVATION

SCALE 1:50

PANEL 65					
PANEL SIZE	DESIGN	AS CONSTRUCTED	PANEL SIZE	DESIGN	AS CONSTRUCTED
CAGE HEIGHT	13,125	13,925	THICKNESS	1,200	1,200
CAGE WIDTH	6,564	6,564	REO. CAGE MASS	14.3t	14.3t

BAR MARK	BAR SIZE	CHECK	No. OF	CHECK	SPACING	CHECK	LENGTH/WIDTH	CHECK
1	N28		5		300		6,564	
2	N20		17		161*		12,000	
3	N24		24		161*		12,000	
4	N40		41		161		12,000	
5	N40		16		161*		8,900	
6	N40		15		161*		6,000	
7	N32		41		161		3,900	
8	N20		17		161*		3,050	
9	N24		24		161*		3,050	
100	N16		40		334		8,628	
101	N16		64		334		7,552	
102	N12		200		334		2,793	
103	N/A		N/A		N/A		N/A	
104	N/A		N/A		N/A		N/A	
105	N16		160		334		1,212	
106	N16		8		334		1,212	

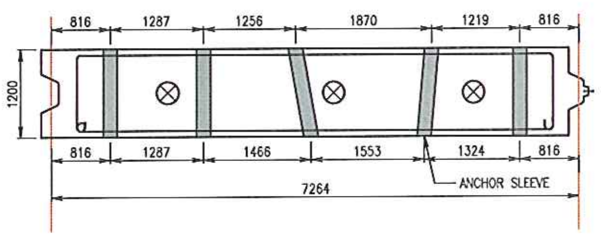
* NOTE: BARS 2 AND 3 IN SAME LAYER COMBINED SPACING TO BE 161mm.

* NOTE: BARS 5 AND 6 IN SAME LAYER COMBINED SPACING TO BE 161mm.

* NOTE: BARS 8 AND 9 IN SAME LAYER COMBINED SPACING TO BE 161mm.

NOTE: BARS 106 USED LOCALLY AT ANCHOR RESERVATIONS AS REQUIRED

CAGE BUILT TO SUIT TOE LEVEL OF RL -12.00 AND THEN EXTENDED TO SUIT STEPPED TOE LEVEL OF RL -12.90, RL -12.4 & RL -12.3



PANEL P65 – KEY DIAGRAM

THOROUGH VISUAL CHECK OF ALL CAGES WILL BE MADE UPON ARRIVAL ON SITE.

ALL HORIZONTAL STEEL WILL BE TIED TO THE MAIN BARS (EVERY THREE MAIN BARS) WITH DOUBLE TYING WIRE.

ALL LIFTING AND POSITIONING BARS WILL BE MADE OF MILD STEEL OF MINIMUM YIELD STRENGTH: 235MPA IF IN DOUBT WITH THE LIFTING PROCEDURE, PLEASE CONTACT THE DESIGN ENGINEER.

ALL MAIN BARS SUPPORTING A LIFTING OR POSITIONING BAR WILL BE WELDED TO THE TOP 8 HORIZONTAL FRAMES.

* INDICATES REINFORCEMENT MARKED IS FOR ERECTION AND LIFTING AND IS NOT PART OF THE STRUCTURAL CAGE. POSITIONING BARS TO BE DETERMINED ON SITE.

LEVELS SHOWN ARE RELATIVE TO AUSTRALIAN DATUM mAHD.

REFER TO DRAWING SZ0306502 FOR SECTIONS.
REFER TO DRAWING SZ0300052 FOR DETAILS

CONCRETE NOTES

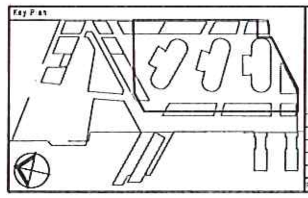
MINIMUM CONCRETE STRENGTH AT 28 DAYS

LOCATION	F'c
ALL ELEMENTS	50 MPa

COVER TO REINFORCEMENT

LOCATION	COVER
ALL ELEMENTS	75mm Min.

AS BUILT



Rev.	Item	Revision Description	Date
E		AS BUILT	29.06.12
D		ANCHOR RESERVATIONS AMENDED	15.03.12
C		ISSUED FOR CONSTRUCTION	06.02.12
B		LEND LEASE REVIEW	25.01.12
A		LEND LEASE REVIEW	14.12.11

Contractors:
Menard Bachy
Level 3
13-15 Lyonpark Road
Macquarie Park NSW 2113
+61 2 9491 7100
MENARD BACHY REVIEW BY: Malcolm Wakefield 29.06.12

Designers:
Coffey Geotechnics Pty. Ltd.
8/12 Mars Road
Lane Cove West NSW 2066
Ph: +61 2 9911 1000

In association with:
Paul Davis Rajalingam
Smart Structures
Ground Floor
55 Chandos St
St Leonards NSW 2065
Ph: +61 2 9004 8855
paul davis rajalingam
SMART STRUCTURES
ACN 113 466 514
PDR Job Number: 20101330
PDR APPROVED FOR STRUCTURAL: Paul Davis 29.06.12

Principal: Lend Lease

Developer	Lend Lease
Project Management & Construction	Lend Lease
Design	Lend Lease

30 The Bond 30 Hickson Road
Millers Point NSW 2000
www.lendlease.com

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Project: BARANGAROO SOUTH

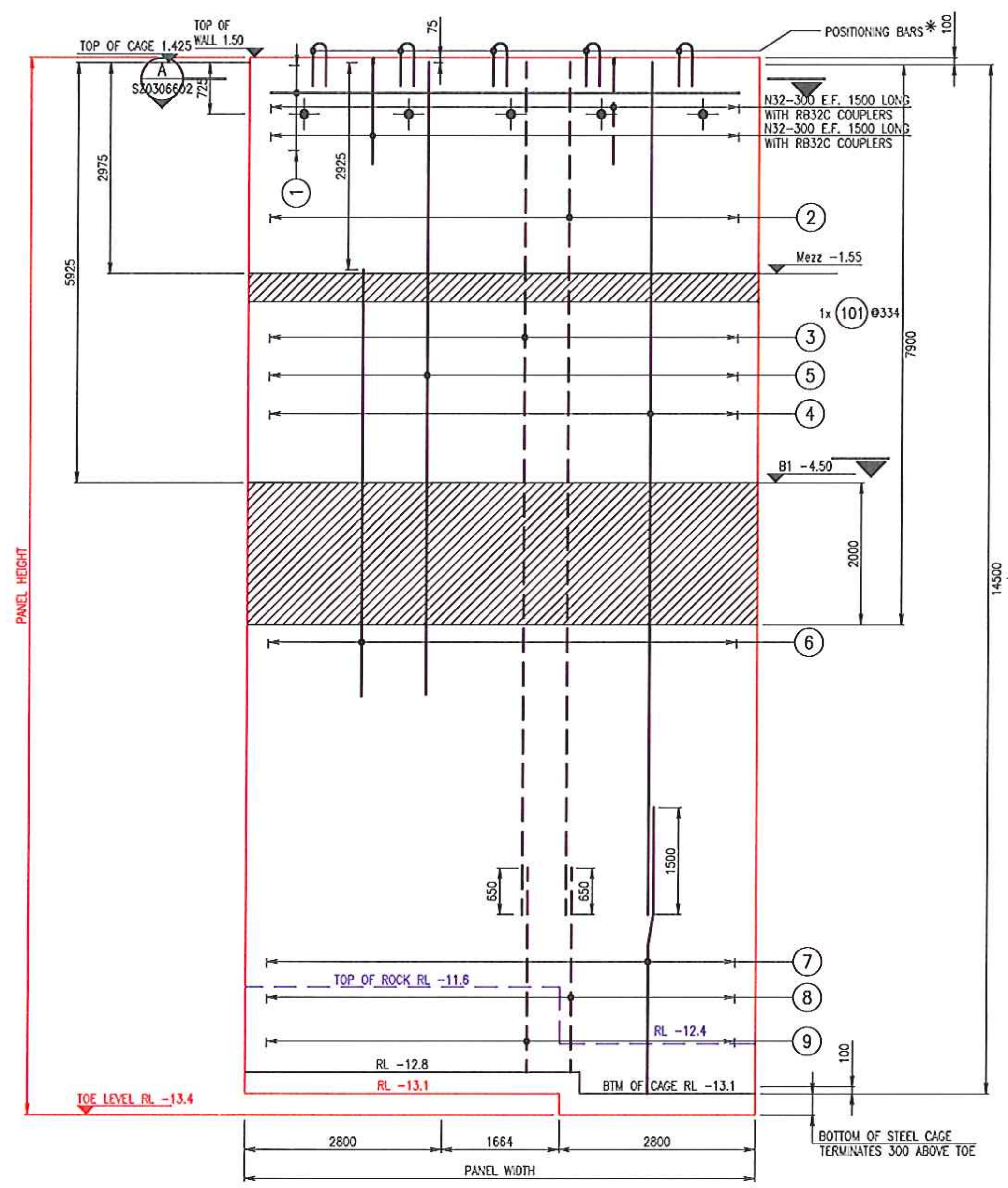
Title: SHOP DRAWING FOR D-WALL PANEL SMA WEST (P64 TO P68) ELEVATION PANEL P65

Drawn By	Date	Purpose	Checked By	Date	Approved By	Date
R.C.L	29.06.12	As Built	G. ISEPPI	29.06.12	P. DAVIS	29.06.12

SCALE 1:50

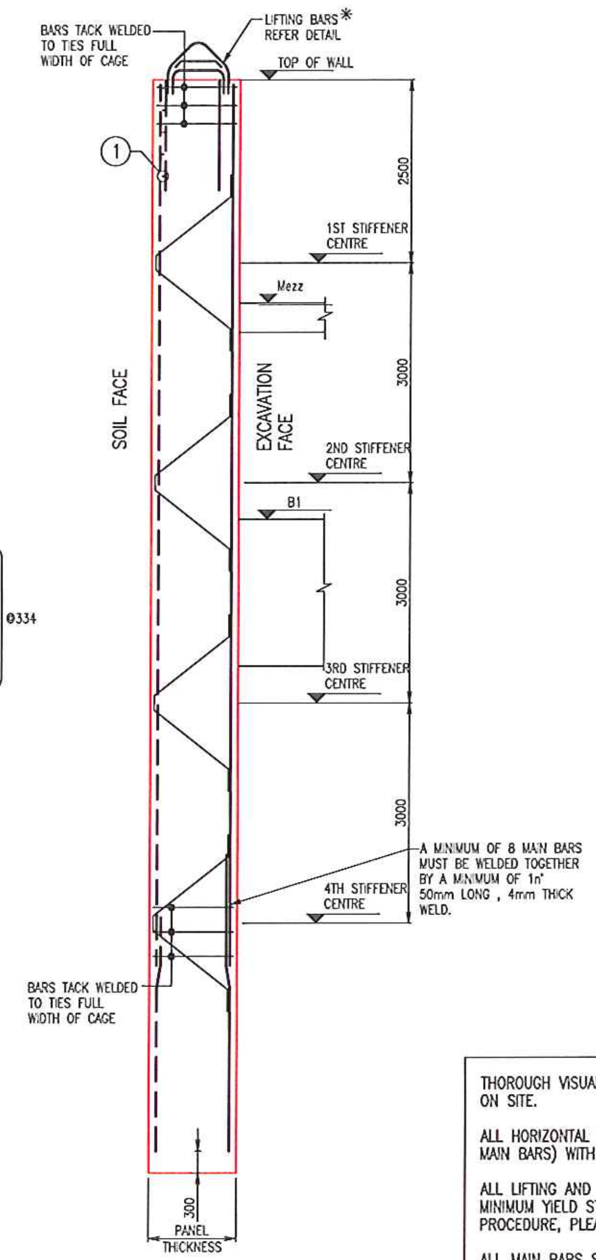
Project No.	Site No.	Drawing No.	Revision
161136	BB1	SZ0306501	E

A1



PANEL ELEVATION

SCALE 1:50



SIDE ELEVATION

SCALE 1:50

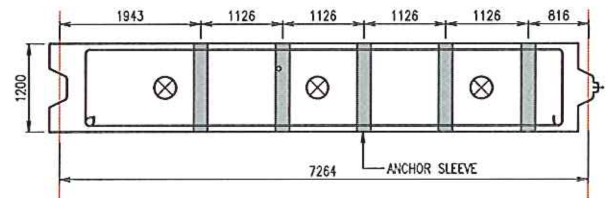
PANEL 66

PANEL SIZE	DESIGN	AS CONSTRUCTED	PANEL SIZE	DESIGN	AS CONSTRUCTED
CAGE HEIGHT	14,625	14,525	THICKNESS	1,200	1,200
CAGE WIDTH	6,564	6,564	REO. CAGE MASS	15.7t	15.6t

BAR MARK	BAR SIZE	CHECK	No. OF	CHECK	SPACING	CHECK	LENGTH/WIDTH	CHECK
1	N28		5		300		6,564	
2	N20		17		161*		12,000	
3	N24		24		161*		12,000	
4	N40		41		161		12,000	
5	N40		16		161*		8,900	
6	N40		15		161*		6,000	
7	N32		41		161		4,125	
8	N20		17		161*		3,275	
9	N24		24		161*		3,275	
100	N16		45		334		8,628	
101	N16		69		334		7,552	
102	N12		270		334		2,793	
103	N/A		N/A		N/A		N/A	
104	N/A		N/A		N/A		N/A	
105	N16		90		334		1,212	

* NOTE: BARS 2 AND 3 IN SAME LAYER COMBINED SPACING TO BE 161mm.
* NOTE: BARS 5 AND 6 IN SAME LAYER COMBINED SPACING TO BE 161mm.
* NOTE: BARS 8 AND 9 IN SAME LAYER COMBINED SPACING TO BE 161mm.

CAGE BUILT TO SUIT TOE LEVEL OF RL -13.50 AND THEN TRIMMED TO SUIT STEPPED TOE LEVEL OF RL -13.40 & -13.10



PANEL P66 – KEY DIAGRAM

THOROUGH VISUAL CHECK OF ALL CAGES WILL BE MADE UPON ARRIVAL ON SITE.

ALL HORIZONTAL STEEL WILL BE TIED TO THE MAIN BARS (EVERY THREE MAIN BARS) WITH DOUBLE TYING WIRE.

ALL LIFTING AND POSITIONING BARS WILL BE MADE OF MILD STEEL OF MINIMUM YIELD STRENGTH: 235MPA IF IN DOUBT WITH THE LIFTING PROCEDURE, PLEASE CONTACT THE DESIGN ENGINEER.

ALL MAIN BARS SUPPORTING A LIFTING OR POSITIONING BAR WILL BE WELDED TO THE TOP 8 HORIZONTAL FRAMES.

* INDICATES REINFORCEMENT MARKED IS FOR ERECTION AND LIFTING AND IS NOT PART OF THE STRUCTURAL CAGE. POSITIONING BARS TO BE DETERMINED ON SITE.

LEVELS SHOWN ARE RELATIVE TO AUSTRALIAN DATUM mAHD.

REFER TO DRAWING SZ0306602 FOR SECTIONS.
REFER TO DRAWING SZ0300052 FOR DETAILS

CONCRETE NOTES

MINIMUM CONCRETE STRENGTH AT 28 DAYS

LOCATION	F'c
ALL ELEMENTS	50 MPa

COVER TO REINFORCEMENT

LOCATION	COVER
ALL ELEMENTS	75mm Min.

AS BUILT

Rev.	Revision Description	Date
D	AS BUILT	29.06.12
C	ISSUED FOR CONSTRUCTION	06.02.12
B	LEND LEASE REVIEW	25.01.12
A	LEND LEASE REVIEW	14.12.11

Contractors: Menard Bachy, Level 3, 13-15 Lyonpark Road, Macquarie Park NSW 2113. +61 2 8431 7100. menard BACHY
MENARD BACHY REVIEW BY: Malcolm Wakefield 29.06.12

Designers: Coffey Geotechnics Pty Ltd, 8/12 Mars Road, Lane Cove West NSW 2066. Ph: +61 2 9911 1000. coffey geotechnics

In association with: Paul Davis Rajalingam Smart Structures, Ground Floor, 55 Chandos St, St Leonards NSW 2065. Ph: +61 2 9004 8855. paul davis rajalingam SMART STRUCTURES
FOR APPROVED FOR STRUCTURAL: Paul Davis 29.06.12

Principal: Lend Lease

Developer	Lend Lease
Project Management & Construction	Lend Lease
Design	Lend Lease

30 The Bond 30 Hickson Road Millers Point NSW 2000 www.lendlease.com

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Project: BARANGAROO SOUTH

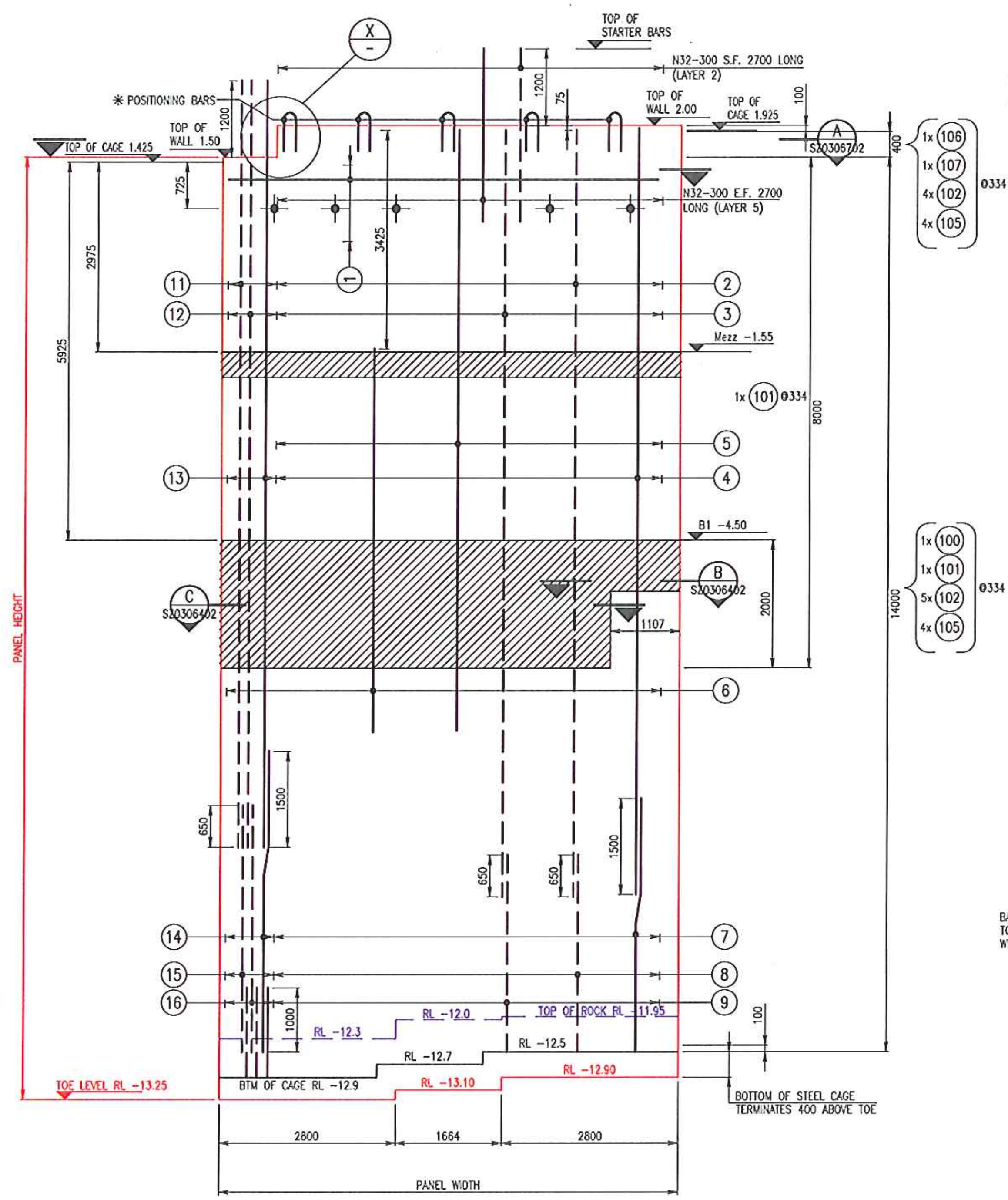
Title: SHOP DRAWING FOR D-WALL PANEL SMA WEST (P64 TO P68) ELEVATION PANEL P66

Drawn By	Date	Purpose	Checked By	Date	Approved By	Date
R.C.L.	29.06.12	As Built	G. ISEPPI	29.06.12	P. DAVIS	29.06.12

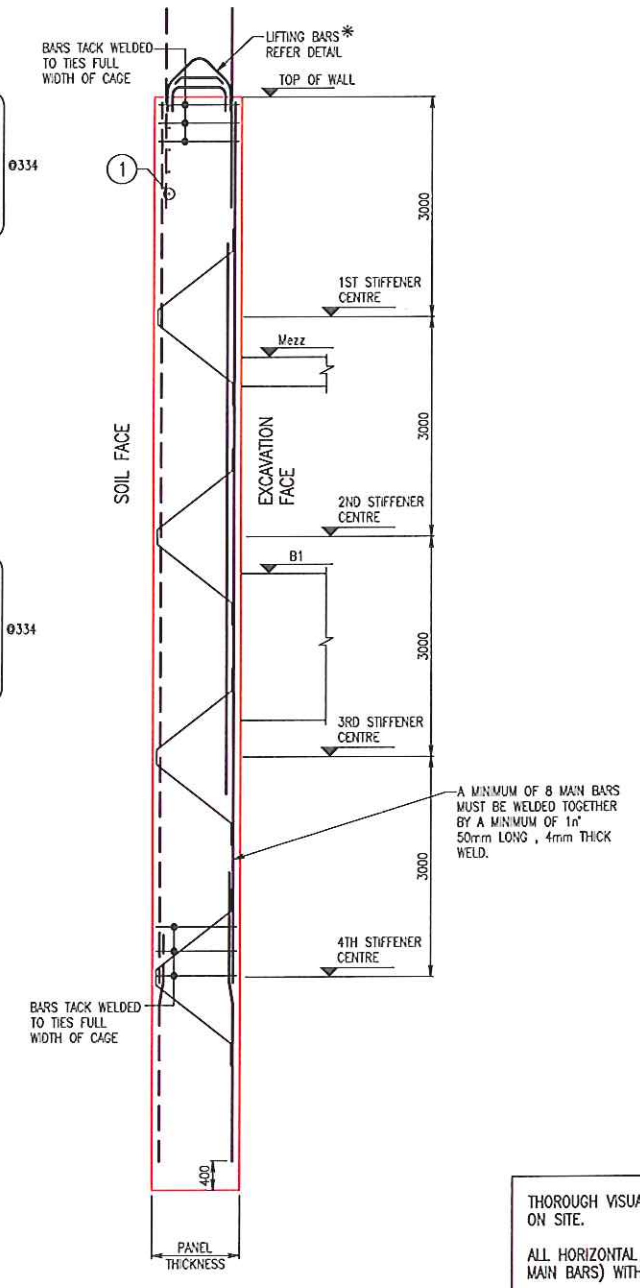
SCALE 1:50

Project No.	Site No.	Drawing No.	Revision
161136	BB1	SZ0306601	D

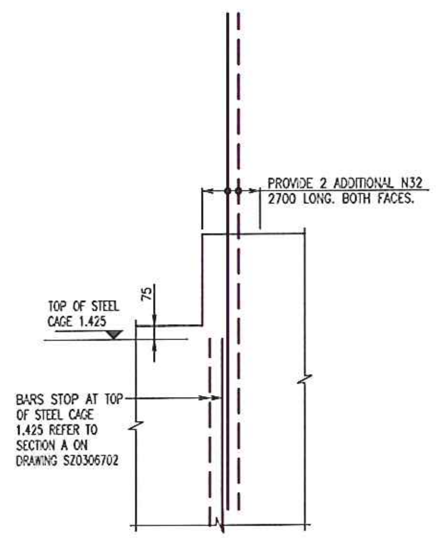
A1



PANEL ELEVATION



SIDE ELEVATION
SCALE 1:50



DETAIL X
SCALE - 1:20

CAGE BUILT TO SUIT TOE LEVEL OF RL -12.80 AND THEN EXTENDED TO SUIT STEPPED TOE LEVEL OF RL -13.25, RL -13.10 & RL -12.90

PANEL 67					
PANEL SIZE	DESIGN	AS CONSTRUCTED	PANEL SIZE	DESIGN	AS CONSTRUCTED
CAGE HEIGHT	14,425/ 13,925	14400/14900/ 14700/14500	THICKNESS	1,200	1,200
CAGE WIDTH	6,564/ 5,920	6,564/ 5,920	REO. CAGE MASS	15.5t	15.7t

BAR MARK	BAR SIZE	CHECK	No. OF	CHECK	SPACING	CHECK	LENGTH/WIDTH	CHECK
1	N28		5		300		6,564	
2	N20		16		161*		12,000	
3	N24		22		161*		12,000	
4	N40		38		161*		12,000	
5	N40		16		161*		9,400	
6	N40		15		161*		6,000	
7	N32		38		161*		3,925	
8	N20		16		161*		3,075	
9	N24		22		161*		3,075	
10	N/A		N/A		N/A		N/A	
11	N20		1		161*		12,000	
12	N24		2		161*		12,000	
13	N40		3		161*		12,000	
14	N32		3		161*		4,700	
15	N20		1		161*		3,850	
16	N24		2		161*		3,850	
100	N16		43		334		8,628	
101	N16		67		334		7,552	
102	N12		223		334		2,793	
103	N/A		N/A		N/A		N/A	
104	N/A		N/A		N/A		N/A	
105	N16		180		334		1,212	
106	N16		2		334		7,184	
107	N16		2		334		6,108	

* NOTE: BARS 2, 3, 11 AND 12 IN SAME LAYER COMBINED SPACING TO BE 161mm.
* NOTE: BARS 5 AND 6 IN SAME LAYER COMBINED SPACING TO BE 161mm.
* NOTE: BARS 4 AND 13 IN SAME LAYER COMBINED SPACING TO BE 161mm.
* NOTE: BARS 8, 9, 15 AND 16 IN SAME LAYER COMBINED SPACING TO BE 161mm.
* NOTE: BARS 7 AND 14 IN SAME LAYER COMBINED SPACING TO BE 161mm.

THOROUGH VISUAL CHECK OF ALL CAGES WILL BE MADE UPON ARRIVAL ON SITE.

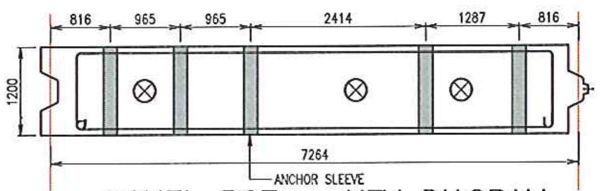
ALL HORIZONTAL STEEL WILL BE TIED TO THE MAIN BARS (EVERY THREE MAIN BARS) WITH DOUBLE TYING WIRE.

ALL LIFTING AND POSITIONING BARS WILL BE MADE OF MILD STEEL OF MINIMUM YIELD STRENGTH: 235MPA IF IN DOUBT WITH THE LIFTING PROCEDURE, PLEASE CONTACT THE DESIGN ENGINEER.

ALL MAIN BARS SUPPORTING A LIFTING OR POSITIONING BAR WILL BE WELDED TO THE TOP 8 HORIZONTAL FRAMES.

* INDICATES REINFORCEMENT MARKED IS FOR ERECTION AND LIFTING AND IS NOT PART OF THE STRUCTURAL CAGE. POSITIONING BARS TO BE DETERMINED ON SITE.

LEVELS SHOWN ARE RELATIVE TO AUSTRALIAN DATUM mAHD.



PANEL P67 – KEY DIAGRAM

REFER TO DRAWING SZ0306702 FOR SECTIONS.
REFER TO DRAWING SZ0300052 FOR DETAILS

CONCRETE NOTES

MINIMUM CONCRETE STRENGTH AT 28 DAYS

LOCATION	F'c
ALL ELEMENTS	50 MPa

COVER TO REINFORCEMENT

LOCATION	COVER
ALL ELEMENTS	75mm Min.

AS BUILT

Rev.	Revision Description	Date
D	AS BUILT	29.06.12
C	ISSUED FOR CONSTRUCTION	06.02.12
B	LEND LEASE REVIEW	25.01.12
A	LEND LEASE REVIEW	14.12.11

Contractors: Menard Bachy, Level 3, 13-15 Lyonpark Road, Macquarie Park NSW 2113, +61 2 9431 7100 — menard BACHY

MENARD BACHY REVIEW BY: Malcolm Wakefield 29.06.12

Designers: Coffey Geotechnics Pty. Ltd. — coffey geotechnics

In association with: paul davis rajalingam SMART STRUCTURES

FOR APPROVED FOR STRUCTURAL: Paul Davis 29.06.12

Lend Lease — Developer: Lend Lease; Project Management & Construction: Lend Lease; Design: Lend Lease

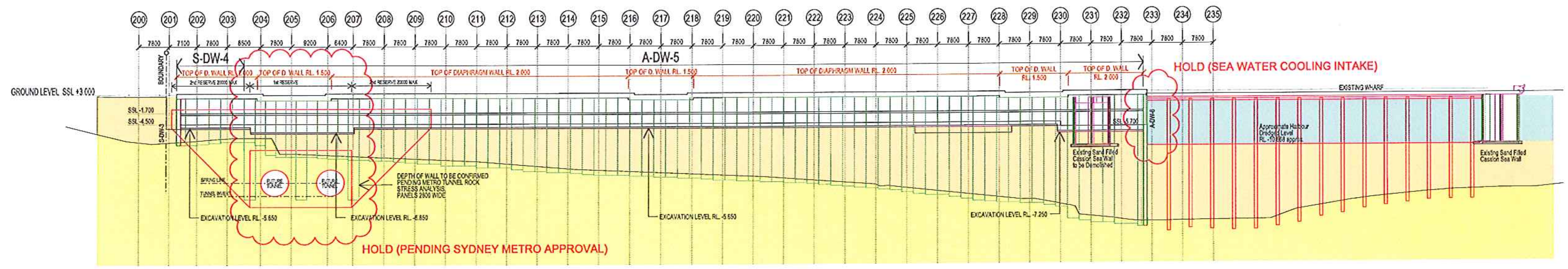
BARANGAROO SOUTH

SHOP DRAWING FOR D-WALL PANEL SMA WEST (P64 TO P68) ELEVATION PANEL P67

SCALE 1:50

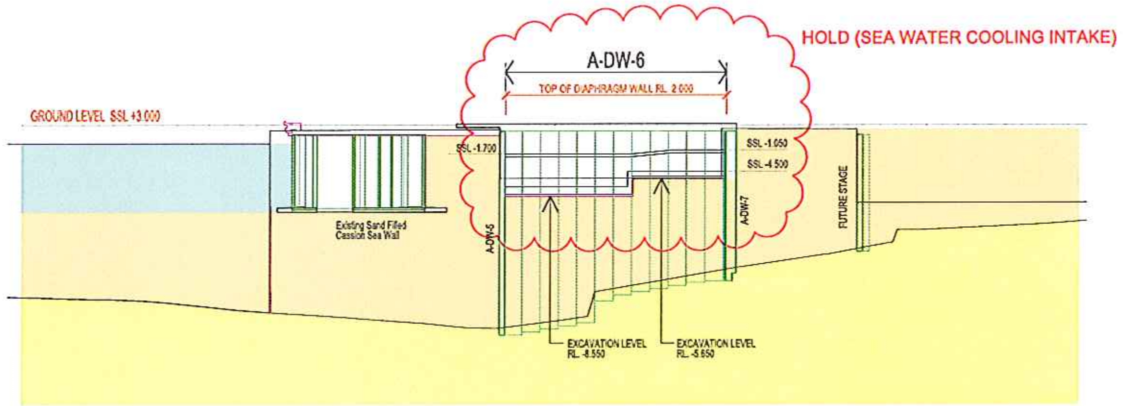
161136 BB1 SZ0306701 D

A1

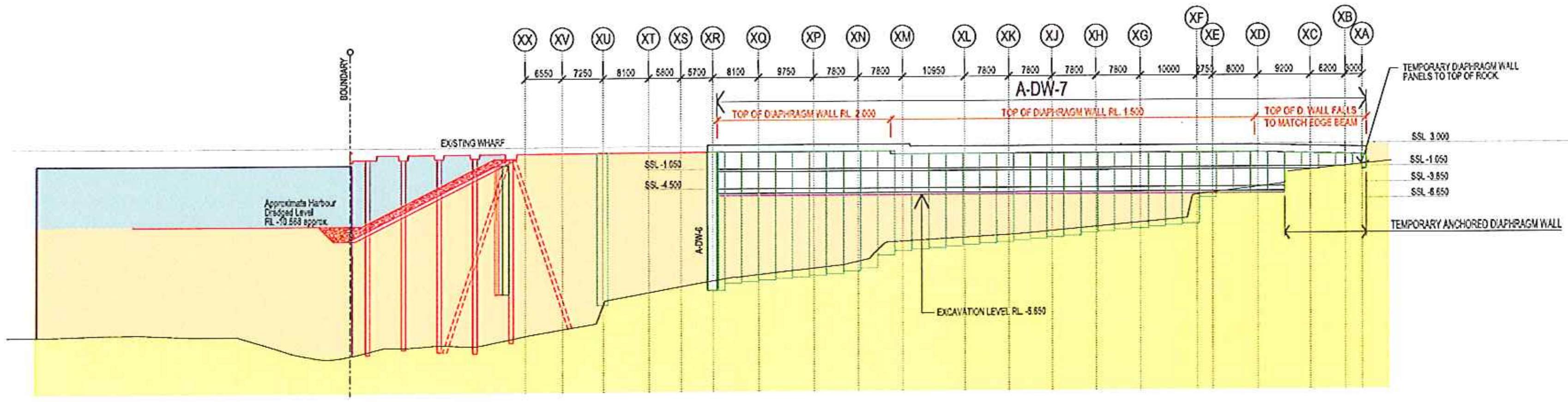


5 SECTION
SCALE 1:500

WESTERN ELEVATION - ADJACENT TO EXISTING SEA WALL

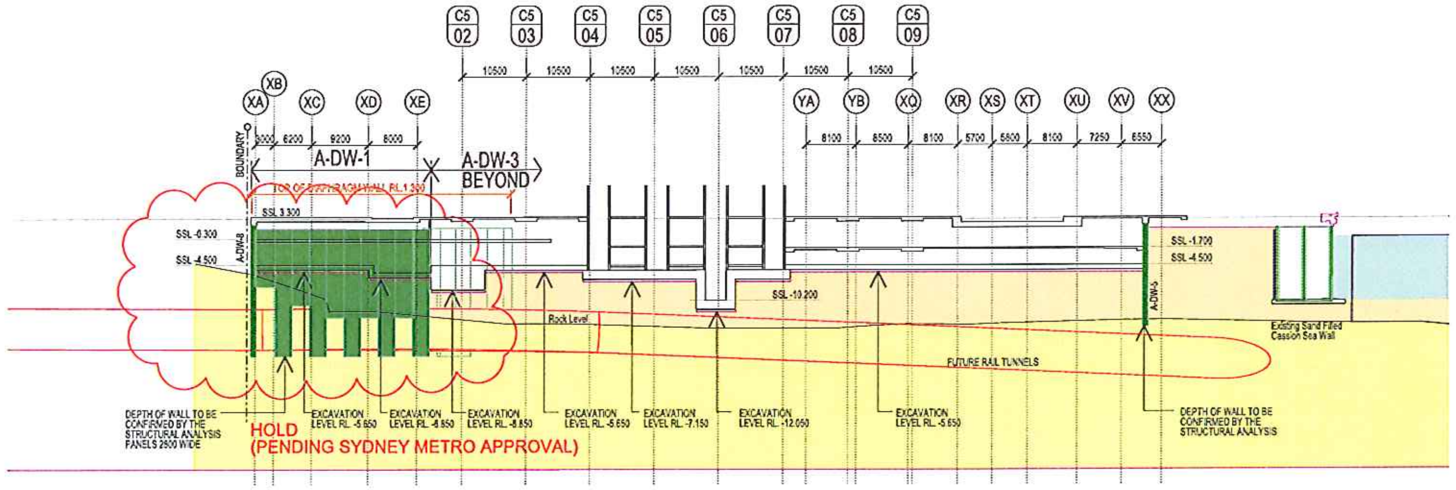


6 SECTION
SCALE 1:500



7 SECTION
SCALE 1:500

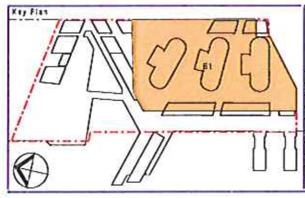
NORTHERN ELEVATION - ADJACENT TO DECCW AREA



8 SECTION
SCALE 1:500

INDICATIVE STRUCTURAL DESIGN
SUBJECT TO FURTHER DESIGN DEVELOPMENT

Key Plan



Rev.	Item	Revision Description	Date
08	-	ISSUED FOR CONTRACT PRICE	16 09 11
07	-	ISSUED FOR CONTRACT PRICE	12 09 11
06	-	ISSUED FOR INFORMATION	03 09 11
05	-	ISSUED FOR INFORMATION	22 07 11
04	-	ISSUED FOR INFORMATION	29 06 11
03	-	ISSUED FOR INFORMATION	10 06 11
02	-	ISSUED FOR INFORMATION	09 06 11
01	-	ISSUED FOR INFORMATION	26 10 10
00	-	ISSUED FOR INFORMATION	30 07 10

NOTE:
ANCHOR POSITIONS NOT SHOWN ON SECTIONS.
FINAL TEMPORARY ANCHOR POSITIONS DETERMINED BY CONTRACTOR
SECTIONS TO BE READ IN CONJUNCTION WITH CONCRETE OUTLINE PLANS AND WITH PERIMETER SHORING WALL LOADING PRINCIPLE DRAWINGS

Lead Architects: RSHP Australia Pty Ltd, Ivan Harbour | Principal Architect, RAIA NSW ARB 8484, Sydney NSW 2000
Collaborating Architects: Lend Lease, Graham W Jones | Principal Architect, FRAIA NSW ARB 4005, ABN 97 000 098 162
Consultant

Principal: Lend Lease
Developer: Lend Lease
Project Management & Construction: Lend Lease
Design: Lend Lease
30 The Bond 30 Hickson Road, Millers Point NSW 2000, www.lendlease.com

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Project: BARANGAROO SOUTH

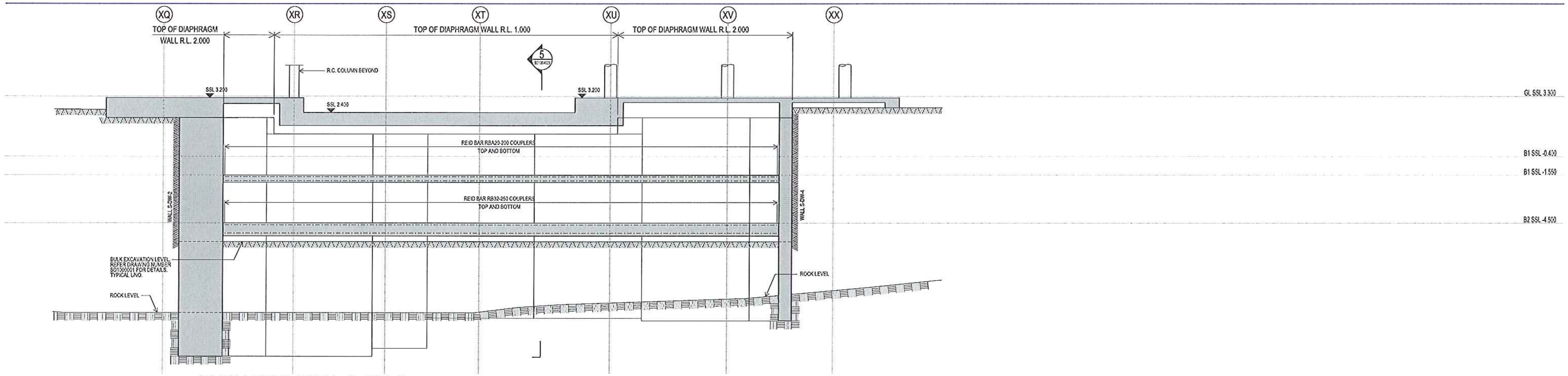
Title: BULK EXCAVATION WALL ELEVATIONS SHEET 2

Drawn By	Date	Purpose	Approved By	Date
BH	27/07/10	TENDER		

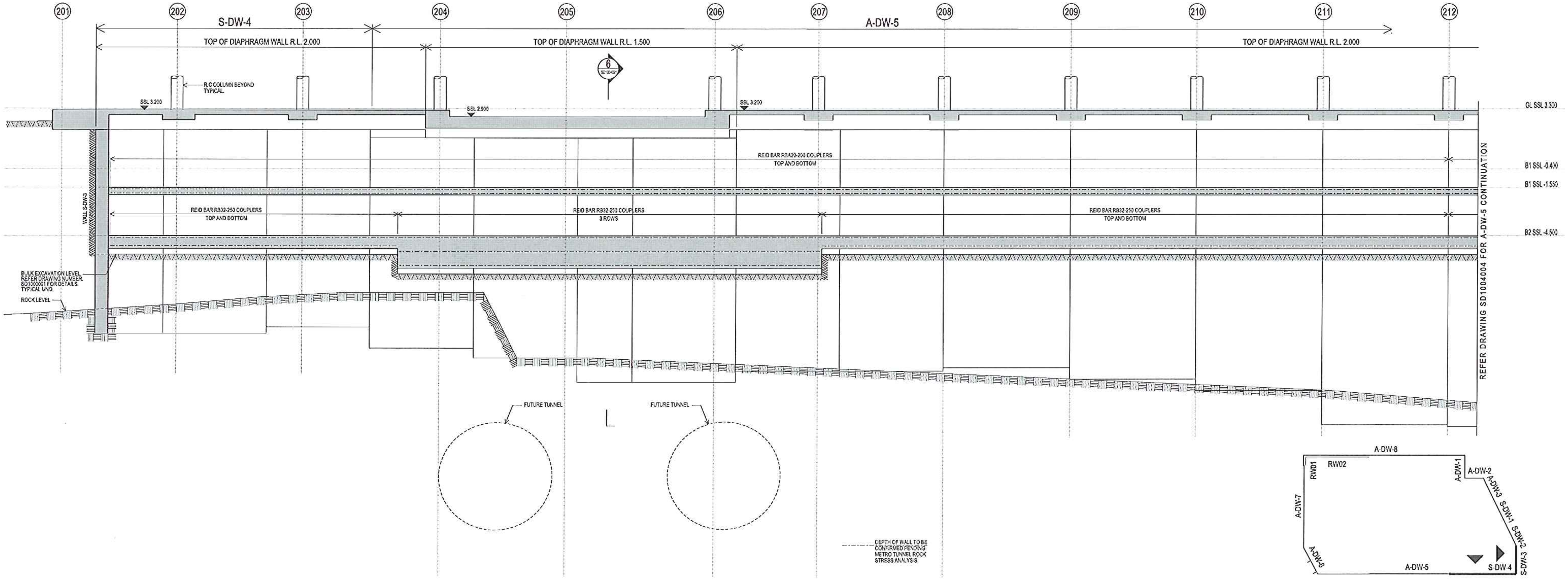
SCALE 1:500 @ B1 1:1250 @ A3 1:500

Project No.	Site No.	Drawing No.	Revision
161804	BB1	SD1000011	08

B1



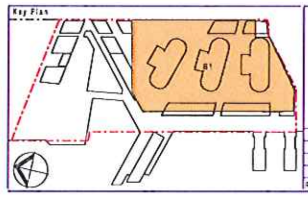
ELEVATION WALL S-DW-3



ELEVATION WALLS S-DW-4 & PART A-DW-5

DIAPHRAGM WALL KEY PLAN

Key Plan



Rev.	Item	Revision Description	Date
02		RE-ISSUED FOR D-WALL DESIGN	21.12.11
		REVISED TO SUIT D WALL CONTRACTORS DWGS	
01		ISSUE FOR D-WALL DESIGN	21.11.11
00		ISSUE FOR INFORMATION	24.10.11

Rev.	Item	Revision Description	Date

NOTES:
ANCHOR POSITIONS NOT SHOWN ON SECTIONS.
FINAL TEMPORARY ANCHOR POSITIONS DETERMINED BY CONTRACTOR

SECTIONS TO BE READ IN CONJUNCTION WITH CONCRETE OUTLINE PLANS AND WITH PERIMETER SHORING WALL LOADING PRINCIPLE DRAWINGS

COUPLER SETOUTS TO ADJACENT DIAPHRAGM WALL PANELS AT CORNER JUNCTIONS SHALL BE OFFSET TO ALLOW OVERLAPPING LAYERS.

Lead Architects: RSHP — RSHP Australia Pty Ltd, Ivan Harbour | Principal Architect, RAIA NSW ARB 8454, Sydney NSW 2000

Collaborating Architects: Lend Lease, Graham W Jones | Principal Architect, FRAIA NSW ARB 4005, ABN 97 000 098 162

Consultant

Principal: Lend Lease

Developer	Lend Lease
Project Management & Construction	Lend Lease
Design	Lend Lease

30 The Bond 30 Hickson Road, Millers Point NSW 2000 — www.lendlease.com

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Project: BARANGAROO SOUTH

Title: BULK EXCAVATION WALL ELEVATIONS - SHEET 3 WALLS S-DW-3, 4 & A-DW-5

Drawn By	Date	Purpose	Approved By	Date
VB	27/09/11	PRELIM	Rocco Bressi	22/12/11

0 — 5M
SCALE 1:100 @ B1 1:250 @ A3 — 1:100

Project No	Site No. Drawing No.	Revision
161804	BB1 SD1004003	02

B1

BC5 ZONE - PILE SCHEDULE

TAG	DIAMETER	WORKING LOAD	WORKING LOAD (UPLIFT)	ULTIMATE LOAD	ULTIMATE LOAD (UPLIFT)	TOP OF PILE LEVEL (RL)	TOE LEVEL	REINFORCEMENT	TIES U.N.O	CONCRETE STRENGTH	SHORT TERM 'K' VALUE	LONG TERM 'K' VALUE	MAXIMUM PERMISSIBLE SETOUT ECCENTRICITY AT TOP OF PILE	PERMANENT TENSION PILE
BC5 - P1	1000	6600 kN	1200 kN	8500 kN	3700 kN	-7.230	**	16-N32	N12-300	50 MPa	3324 MN/m	*	118	NO
BC5 - P2	1000	7800 kN	1400 kN	10000 kN	3900 kN	-7.230	**	16-N32	N12-300	50 MPa	3317 MN/m	*	118	NO
BC5 - P3	1000	7800 kN	1400 kN	10000 kN	3900 kN	-7.230	**	16-N32	N12-300	50 MPa	3317 MN/m	*	118	NO
BC5 - P4	1000	6600 kN	1000 kN	8500 kN	3500 kN	-7.230	**	16-N32	N12-300	50 MPa	3139 MN/m	*	118	NO
BC5 - P5	1000	6800 kN	1000 kN	8700 kN	3500 kN	-7.230	**	16-N32	N12-300	50 MPa	3124 MN/m	*	118	NO
BC5 - P6	1150	4200 kN	2900 kN	5400 kN	5500 kN	-7.230	**	22-N36	N12-300	50 MPa	7113 MN/m	*	118	YES
BC5 - P7	1000	6000 kN	2400 kN	7600 kN	5500 kN	-7.230	**	18-N36	N12-300	50 MPa	6301 MN/m	*	118	NO
BC5 - P8	1000	6000 kN	2400 kN	7600 kN	5500 kN	-7.230	**	18-N36	N12-300	50 MPa	6301 MN/m	*	118	NO
BC5 - P9	1000	7500 kN	1200 kN	9600 kN	3700 kN	-7.230	**	16-N32	N12-300	50 MPa	3250 MN/m	*	118	NO
BC5 - P10														
BC5 - P11	1000	4000 kN	1200 kN	5100 kN	3700 kN	-7.230	**	16-N32	N12-300	50 MPa	3557 MN/m	*	118	YES
BC5 - P12	1000	9600 kN	1600 kN	12300 kN	4600 kN	-6.150	**	16-N32	N12-300	50 MPa	5944 MN/m	*	111	NO
BC5 - P13														
BC5 - P14	1000	8500 kN	1100 kN	10900 kN	3800 kN	-6.150	**	16-N32	N12-300	50 MPa	3259 MN/m	*	111	NO
BC5 - P15	1000	7100 kN	1500 kN	9000 kN	3600 kN	-6.150	**	16-N32	N12-300	50 MPa	3191 MN/m	*	111	YES
BC5 - P16														
BC5 - P17														
BC5 - P18	1150	11500 kN	1200 kN	14800 kN	4900 kN	-6.150	**	18-N36	N12-300	50 MPa	5820 MN/m	*	111	NO
BC5 - P19	1000	9600 kN	2300 kN	12300 kN	5200 kN	-6.150	**	18-N36	N12-300	50 MPa	5520 MN/m	*	111	YES
BC5 - P20														
BC5 - P21														
BC5 - P22														
BC5 - P23														
BC5 - P24														
BC5 - P25	1150	11500 kN	1200 kN	14800 kN	4900 kN	-6.150	**	18-N36	N12-300	50 MPa	5820 MN/m	*	111	NO
BC5 - P26	1000	9600 kN	2300 kN	12300 kN	5200 kN	-6.150	**	18-N36	N12-300	50 MPa	5520 MN/m	*	111	YES
BC5 - P27														
BC5 - P28	1000	9100 kN	700 kN	11600 kN	2500 kN	-6.150	**	16-N32	N12-300	50 MPa	5347 MN/m	*	111	NO
BC5 - P29	1000	10200 kN	1500 kN	13100 kN	3900 kN	-6.150	**	16-N32	N12-300	50 MPa	6105 MN/m	*	111	NO
BC5 - P30	1000	6800 kN	1400 kN	8500 kN	2900 kN	-6.150	**	16-N32	N12-300	50 MPa	2728 MN/m	*	111	NO
BC5 - P31														
BC5 - P32														
BC5 - P33														
BC5 - P34														
BC5 - P35	1000	7700 kN	1000 kN	9900 kN	3100 kN	-6.150	**	16-N32	N12-300	50 MPa	2632 MN/m	*	111	NO
BC5 - P36	1000	7700 kN	1000 kN	9900 kN	3100 kN	-6.150	**	16-N32	N12-300	50 MPa	2632 MN/m	*	111	NO
BC5 - P37	1000	10200 kN	1500 kN	13100 kN	3900 kN	-6.150	**	16-N32	N12-300	50 MPa	6105 MN/m	*	111	NO
BC5 - P38	1000	10200 kN	2300 kN	13100 kN	5900 kN	-6.150	**	18-N36	N12-300	50 MPa	6105 MN/m	*	111	NO
BC5 - P39	1000	10200 kN	2300 kN	13100 kN	5900 kN	-6.150	**	18-N36	N12-300	50 MPa	6105 MN/m	*	111	NO
BC5 - P40	1000	9600 kN	1400 kN	12200 kN	3800 kN	-6.150	**	16-N32	N12-300	50 MPa	5307 MN/m	*	111	NO
BC5 - P41	1000	8600 kN	1000 kN	11100 kN	3100 kN	-6.150	**	16-N32	N12-300	50 MPa	5383 MN/m	*	111	NO
BC5 - P42	1000	10200 kN	1500 kN	13100 kN	3900 kN	-6.150	**	16-N32	N12-300	50 MPa	6105 MN/m	*	111	NO
BC5 - P43	1000	10200 kN	1500 kN	13100 kN	3900 kN	-6.150	**	16-N32	N12-300	50 MPa	6105 MN/m	*	111	NO
BC5 - P44	1000	10200 kN	1500 kN	13100 kN	3900 kN	-6.150	**	16-N32	N12-300	50 MPa	6105 MN/m	*	111	NO
BC5 - P45	1000	9600 kN	1400 kN	12200 kN	3800 kN	-6.150	**	16-N32	N12-300	50 MPa	5307 MN/m	*	111	NO
BC5 - P46	1000	9600 kN	1400 kN	12200 kN	3800 kN	-6.150	**	16-N32	N12-300	50 MPa	5307 MN/m	*	111	NO
BC5 - P47														
BC5 - P48														
BC5 - P49														
BC5 - P50														
BC5 - P51														
BC5 - P52	1000	7600 kN	800 kN	9800 kN	2700 kN	-6.150	**	16-N32	N12-300	50 MPa	2575 MN/m	*	111	NO
BC5 - P53	1000	8100 kN	1000 kN	10400 kN	3100 kN	-6.150	**	16-N32	N12-300	50 MPa	2798 MN/m	*	111	NO
BC5 - P54	1000	8100 kN	1000 kN	10400 kN	3100 kN	-6.150	**	16-N32	N12-300	50 MPa	2798 MN/m	*	111	NO
BC5 - P55	1000	8100 kN	1000 kN	10400 kN	3100 kN	-6.150	**	16-N32	N12-300	50 MPa	2798 MN/m	*	111	NO
BC5 - P56	1000	8100 kN	1000 kN	10400 kN	3100 kN	-6.150	**	16-N32	N12-300	50 MPa	2798 MN/m	*	111	NO
BC5 - P57	1000	8100 kN	1000 kN	10400 kN	3100 kN	-6.150	**	16-N32	N12-300	50 MPa	2798 MN/m	*	111	NO
BC5 - P58	1000	8100 kN	1000 kN	10400 kN	3100 kN	-6.150	**	16-N32	N12-300	50 MPa	2798 MN/m	*	111	NO

HOLD

BC5 ZONE - PILE SCHEDULE

TAG	DIAMETER	WORKING LOAD	WORKING LOAD (UPLIFT)	ULTIMATE LOAD	ULTIMATE LOAD (UPLIFT)	TOP OF PILE LEVEL (RL)	TOE LEVEL	REINFORCEMENT	TIES U.N.O	CONCRETE STRENGTH	SHORT TERM 'K' VALUE	LONG TERM 'K' VALUE	MAXIMUM PERMISSIBLE SETOUT ECCENTRICITY AT TOP OF PILE	PERMANENT TENSION PILE
BC5 - P151														
BC5 - P152														
BC5 - P153	1000	900 kN	1700 kN	1200 kN	2900 kN	-7.230	**	18-N36	N12-300	50 MPa	3308 MN/m	*	118	YES
BC5 - P154	1000	8000 kN	1300 kN	10000 kN	3200 kN	-7.230	**	16-N32	N12-300	50 MPa	2767 MN/m	*	118	NO
BC5 - P155	1000	7200 kN	1300 kN	9000 kN	3200 kN	-7.230	**	16-N32	N12-300	50 MPa	2827 MN/m	*	118	NO
BC5 - P156	1000	7200 kN	1300 kN	9000 kN	3200 kN	-7.230	**	16-N32	N12-300	50 MPa	2654 MN/m	*	118	NO
BC5 - P157	1000	6300 kN	1700 kN	7900 kN	3900 kN	-7.230	**	16-N32	N12-300	50 MPa	3442 MN/m	*	118	NO
BC5 - P158	1150	1200 kN	2500 kN	1500 kN	4500 kN	-7.230	**	22-N36	N12-300	50 MPa	4260 MN/m	*	118	YES
BC5 - P159	1000	6300 kN	1700 kN	7900 kN	3900 kN	-7.230	**	16-N32	N12-300	50 MPa	3442 MN/m	*	118	NO
BC5 - P160	1000	7500 kN	1600 kN	9000 kN	3500 kN	-8.050	**	16-N32	N12-300	50 MPa	3067 MN/m	*	124	NO
BC5 - P161	1000	7500 kN	1600 kN	9000 kN	3500 kN	-8.050	**	16-N32	N12-300	50 MPa	3067 MN/m	*	124	NO
BC5 - P162	1000	7500 kN	1600 kN	9000 kN	3500 kN	-8.050	**	16-N32	N12-300	50 MPa	3067 MN/m	*	124	NO
BC5 - P163	1000	7500 kN	1600 kN	9000 kN	3500 kN	-8.050	**	16-N32	N12-300	50 MPa	3067 MN/m	*	124	NO
BC5 - P164	1000	1200 kN	2000 kN	1600 kN	3400 kN	-6.150	**	18-N36	N12-300	50 MPa	4607 MN/m	*	111	YES
BC5 - P165	1000	6300 kN	1400 kN	7900 kN	2900 kN	-6.150	**	16-N32	N12-300	50 MPa	2767 MN/m	*	111	NO
BC5 - P166	1000	6300 kN	1400 kN	7900 kN	2900 kN	-6.150	**	16-N32	N12-300	50 MPa	2767 MN/m	*	111	NO
BC5 - P167	1000	6300 kN	1400 kN	7900 kN	2900 kN	-6.150	**	16-N32	N12-300	50 MPa	2767 MN/m	*	111	NO
BC5 - P168	1000	6300 kN	1400 kN	7900 kN	2900 kN	-6.150	**	16-N32	N12-300	50 MPa	2767 MN/m	*	111	NO
BC5 - P169	1000	6300 kN	1400 kN	7900 kN	2900 kN	-6.150	**	16-N32	N12-300	50 MPa	2767 MN/m	*	111	NO
BC5 - P170	1000	5000 kN	700 kN	6300 kN	2000 kN	-8.050	**	16-N32	N12-300	50 MPa	2252 MN/m	*	124	NO
BC5 - P171	1000	5000 kN	700 kN	6300 kN	2000 kN	-8.050	**	16-N32	N12-300	50 MPa	2252 MN/m	*	124	NO
BC5 - P172	1000	5000 kN	700 kN	6300 kN	2000 kN	-8.050	**	16-N32	N12-300	50 MPa	2252 MN/m	*	124	NO
BC5 - P173	1000	5000 kN	700 kN	6300 kN	2000 kN	-8.050	**	16-N32	N12-300	50 MPa	2252 MN/m	*	124	NO
BC5 - P174	1000	2600 kN	800 kN	3300 kN	1300 kN	-8.050	**	16-N32	N12-300	50 MPa	2329 MN/m	*	124	YES
BC5 - P175	1000	2600 kN	800 kN	3300 kN	1300 kN	-8.050	**	16-N32	N12-300	50 MPa	2329 MN/m	*	124	YES
BC5 - P176	1150	1900 kN	3100 kN	2500 kN	5300 kN	-6.150	**	22-N36	N12-300	50 MPa	6695 MN/m	*	111	YES

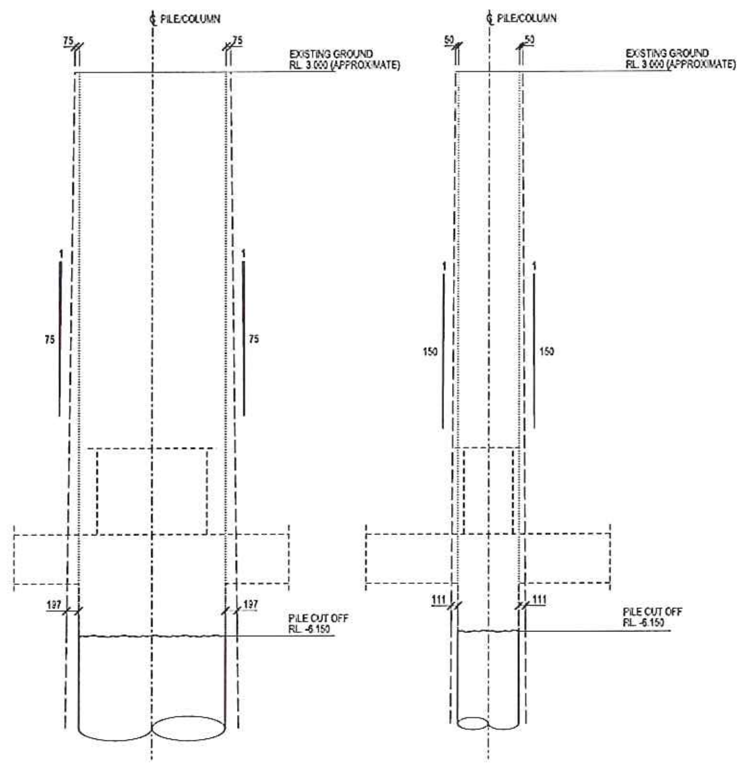
HOLD

TRANSFER SLAB - PILE SCHEDULE

TAG	DIAMETER	WORKING LOAD	WORKING LOAD (UPLIFT)	ULTIMATE LOAD	ULTIMATE LOAD (UPLIFT)	TOP OF PILE LEVEL (RL)	APPROX BTM OF SLEEVE (RL)	APPROX TOE LEVEL (RL) **	REINFORCEMENT	TIES U.N.O	CONCRETE STRENGTH	SHORT TERM 'K' VALUE	LONG TERM 'K' VALUE	MAXIMUM PERMISSIBLE SETOUT ECCENTRICITY AT TOP OF PILE	PERMANENT TENSION PILE
BC5 - TP100	1150	2400 kN	-1600 kN	3000 kN	-2000 kN	-6.350	-		18-N32	N12-300	50 MPa	*	*	112	YES
BC5 - TP101	1150	8000 kN	-1600 kN	10000 kN	-2000 kN	-6.350	-		18-N32	N12-300	50 MPa	*	*	112	YES
BC5 - TP102	1150	2400 kN	-400 kN	3000 kN	-500 kN	-6.350	-		18-N32	N12-300	50 MPa	*	*	112	NO
BC5 - TP103	1150	8000 kN	-2400 kN	10000 kN	-3000 kN	-6.350	-		20-N32	N12-300	50 MPa	*	*	112	YES
BC5 - TP104	1150	8000 kN	-2000 kN	10000 kN	-2500 kN	-6.350	-		18-N32	N12-300	50 MPa	*	*	112	YES
BC5 - TP105	1150	9600 kN	-2000 kN	12000 kN	-2500 kN	-6.350	-		18-N32	N12-300	50 MPa	*	*	112	NO
BC5 - TP106	1150	9600 kN	-2800 kN	12000 kN	-3500 kN	-6.350	-		22-N32	N12-300	50 MPa	*	*	112	YES
BC5 - TP107	1150	11200 kN	-2800 kN	14000 kN	-3500 kN	-6.350	-		22-N32	N12-300	50 MPa	*	*	112	YES
BC5 - TP108	1150	16000 kN	-3200 kN	20000 kN	-4000 kN	-6.350	-		24-N36	N12-300	50 MPa	*	*	112	NO
BC5 - TP109	1150	8800 kN	-3200 kN	11000 kN	-4000 kN	-6.350	-		24-N36	N12-300	50 MPa	*	*	112	YES
BC5 - TP110	1150	10400 kN	-3200 kN	13000 kN	-4000 kN	-6.350	-		24-N36	N12-300	50 MPa	*	*	112	YES
BC5 - TP111	1150	16800 kN	-3200 kN	21000 kN	-4000 kN	-6.350	-		24-N36	N12-300	50 MPa	*	*	112	NO
BC5 - TP112	1150	11200 kN	-3700 kN	14000 kN	-5000 kN	-6.350	-		26-N36	N12-300	50 MPa	*	*	112	YES
BC5 - TP113	1150	12000 kN	-1600 kN	15000 kN	-2000 kN	-6.350	-		18-N32	N12-300	50 MPa	*	*	112	YES
BC5 - TP114	1150	16800 kN	-3200 kN	21000 kN	-4000 kN	-6.350	-		24-N36	N12-300	50 MPa	*	*	112	NO
BC5 - TP115	1150	14400 kN	-3700 kN	18000 kN	-5000 kN	-6.350	-		26-N36	N12-300	50 MPa	*	*	112	YES
BC5 - TP116	1150	7200 kN	-1600 kN	9000 kN	-2000 kN	-6.350	-		18-N32	N12-300	50 MPa	*	*	112	YES
BC5 - TP117	1150	7200 kN	-1600 kN	9000 kN	-2000 kN	-6.350	-		18-N32	N12-300	50 MPa	*	*	112	YES
BC5 - TP118	1150	16000 kN	-	20000 kN	-	-6.350	-		18-N36	N12-300	50 MPa	*	*	112	NO
BC5 - TP119	1500	24000 kN	-	30000 kN	-	-6.350	-		18-N36	N12-300	50 MPa	*	*	112	NO
BC5 - TP120	1150	12800 kN	-	16000 kN	-	-6.350	-		18-N36	N12-300	50 MPa	*	*	112	NO
BC5 - TP121	1150	8400 kN	-	10500 kN	-	1.950	-		18-N36	N12-300	50 MPa	*	*	57	NO
BC5 - TP122	1150	7600 kN	-	9500 kN	-	1.950	-		18-N36	N12-300	50 MPa	*	*	57	NO
BC5 - TP123	1150	6000 kN	-	7500 kN	-	1.950	-		18-N36	N12-300	50 MPa	*	*	57	NO

NOTES.

1. MAXIMUM LONG TERM PILE SETTLEMENT UNDER WORKING LOAD AT THE TOE LEVEL SHALL BE 0.3% OF THE PILE DIAMETER.
2. MAX DIFFERENTIAL SETTLEMENT BETWEEN ADJACENT PILES SHALL BE 10mm.
3. (*) GEOTECHNICAL CONSULTANT SHALL PROVIDE SHORT TERM AND LONG TERM ROCK STIFFNESS (k VALUES) FOR ALL PILES.
4. (**) GEOTECHNICAL CONSULTANT SHALL PROVIDE TOE LEVELS REQUIRED FOR GEOTECHNICAL CAPACITY.
5. PILES ARE TO HAVE SULPHATE RESISTANCE ADMIXTURE.
6. COVER TO REINFORCEMENT TO BE 75mm U.N.O.
7. PILES WITHIN THE SYDNEY METRO 1ST RESERVE ARE TO BE SLEEVED TO A LEVEL DETERMINED BY THE GEOTECHNICAL ENGINEER.
8. PILES WITHIN THE SYDNEY METRO 2ND RESERVE ARE TO BE SLEEVED TO A LEVEL DETERMINED BY THE GEOTECHNICAL ENGINEER.
9. REFER TO COFFEY GEOTECHNICS REPORT GEOTLCOV24015AD-EN "BARANGAROO SOUTH - C5 PILES ADJACENT TO FUTURE SMA TUNNELS" FOR DESIGN PRINCIPLES IN RELATION TO SLEEVING.
10. REFER TO COFFEY GEOTECHNICS REPORT GEOTLCOV24015AD-EY "BARANGAROO SOUTH - TOWER C5 DETAIL DESIGN OF PILE SOCKET LENGTHS" FOR ROCK ZONE CLASSIFICATION AND SOCKET DEPTHS.
11. ALL PILES SHALL BE DESIGNED FOR THE FOLLOWING ADDITIONAL LOADS:
    LATERAL 200kN ULTIMATE WIND LOAD APPLIED TO THE TOP OF THE PILE.
    ULTIMATE SHEAR FORCE OF 700kN IN ACCORDANCE WITH REPORT GEOTLCOV24015AD-EN.
    ULTIMATE BENDING MOMENT OF 900kN IN ACCORDANCE WITH REPORT GEOTLCOV240415AD-EN

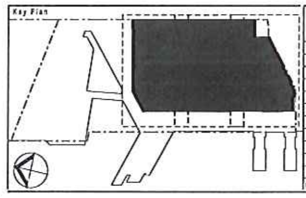


BENTONITE

SEGMENTAL DOUBLE WALL CASING

MAXIMUM PERMISSIBLE PILE SETOUT TOLERANCE

Key Plan



Rev.	Item	Revision Description	Date
D		ISSUED FOR TRANSPORT FOR NSW APPROVAL	05.10.12
	5	REINF REVISED BC5-TP118 AND BC5-TP120	
	4	PILES BC5-TP121 TO BC5-TP123 ADDED	
C	-	ISSUED FOR TRANSFER PILE SOCKET DESIGN	04.09.12
	3	TRANSFER PILE SCHEDULE ADDED, NOTE REVISED	
B	-	ISSUED FOR CONSTRUCTION	08.06.12
	2	SCHEDULE REVISED	
A	-	ISSUED FOR CONSTRUCTION	05.06.12
01	-	RE-ISSUED FOR PILE SOCKET DESIGN	17.05.12
	1	SCHEDULE REVISED	
00	-	ISSUED FOR PILE SOCKET DESIGN	17.04.12

Lead Architects: RSHP — RSHP Australia Pty Ltd, Ivan Harbour | Principal Architect, RAIA NSW ARB 8484, Sydney NSW 2000

Collaborating Architects: Lend Lease — Graham W Jones | Principal Architect, FRAIA NSW ARB 4005, ABN 97 000 098 162

Consultant

Principal: Lend Lease

Developer: Lend Lease
Project Management & Construction: Lend Lease
Design: Lend Lease

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Project: BARANGAROO SOUTH

03
02
01

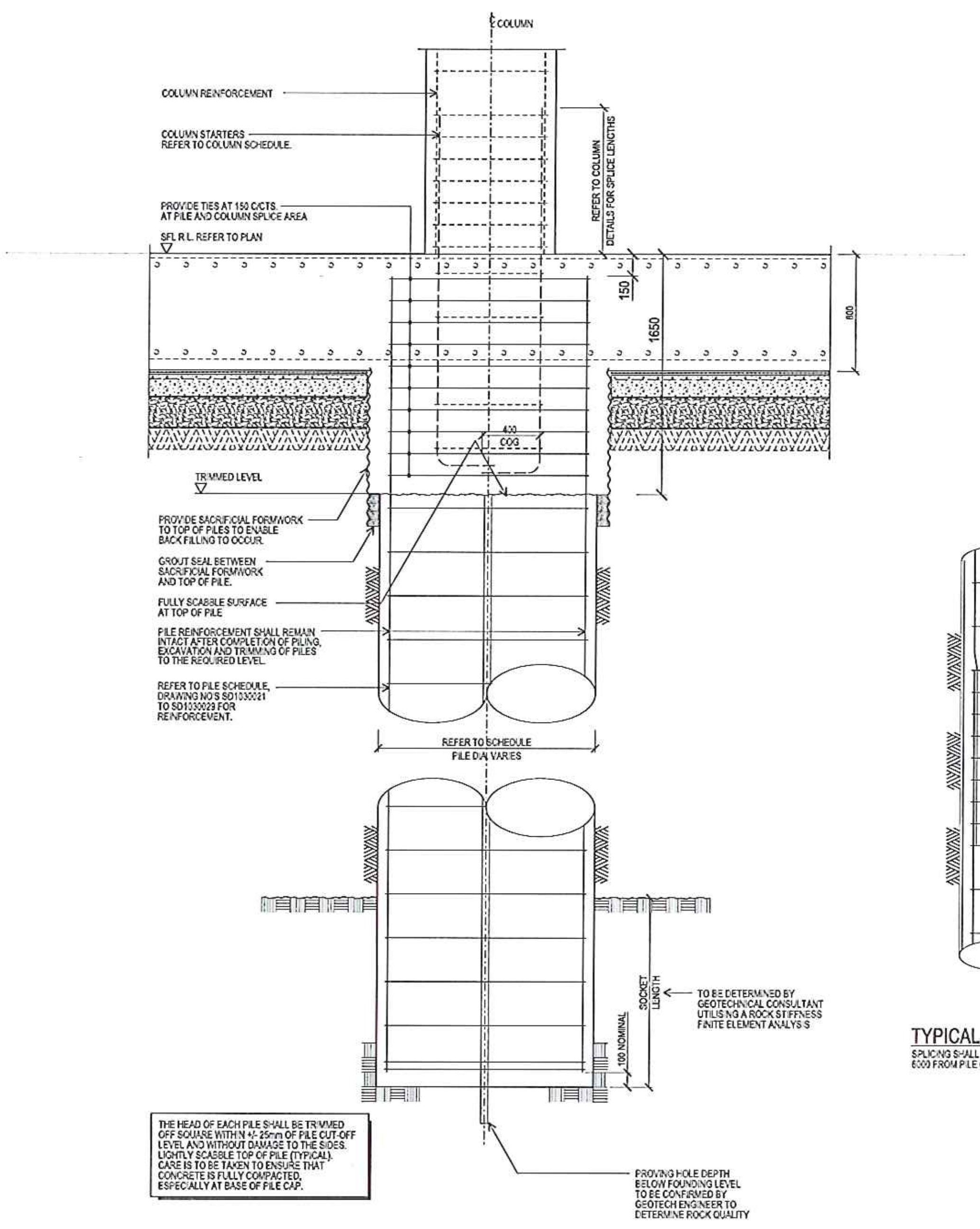
Title: OVERALL SITE PILE SCHEDULE ZONE BC5

Drawn By	Date	Purpose	Approved By	Date
VB	17/05/12	CONSTN		

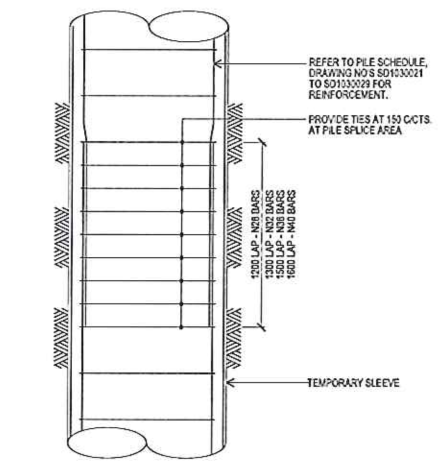
SCALE 1:20 @ B1 — 0 1 — 1:50

Project No.	Site No	Drawing No	Revision
161804	BB1	SD1030026	D

B1

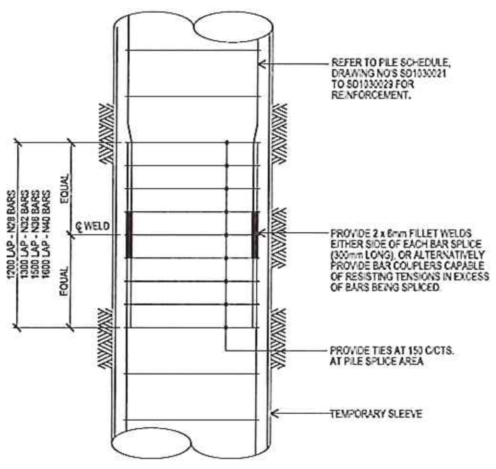


TYPICAL PILE CAP SECTION - SINGLE PILE
FOR BASEMENT AND PODIUM COLUMNS



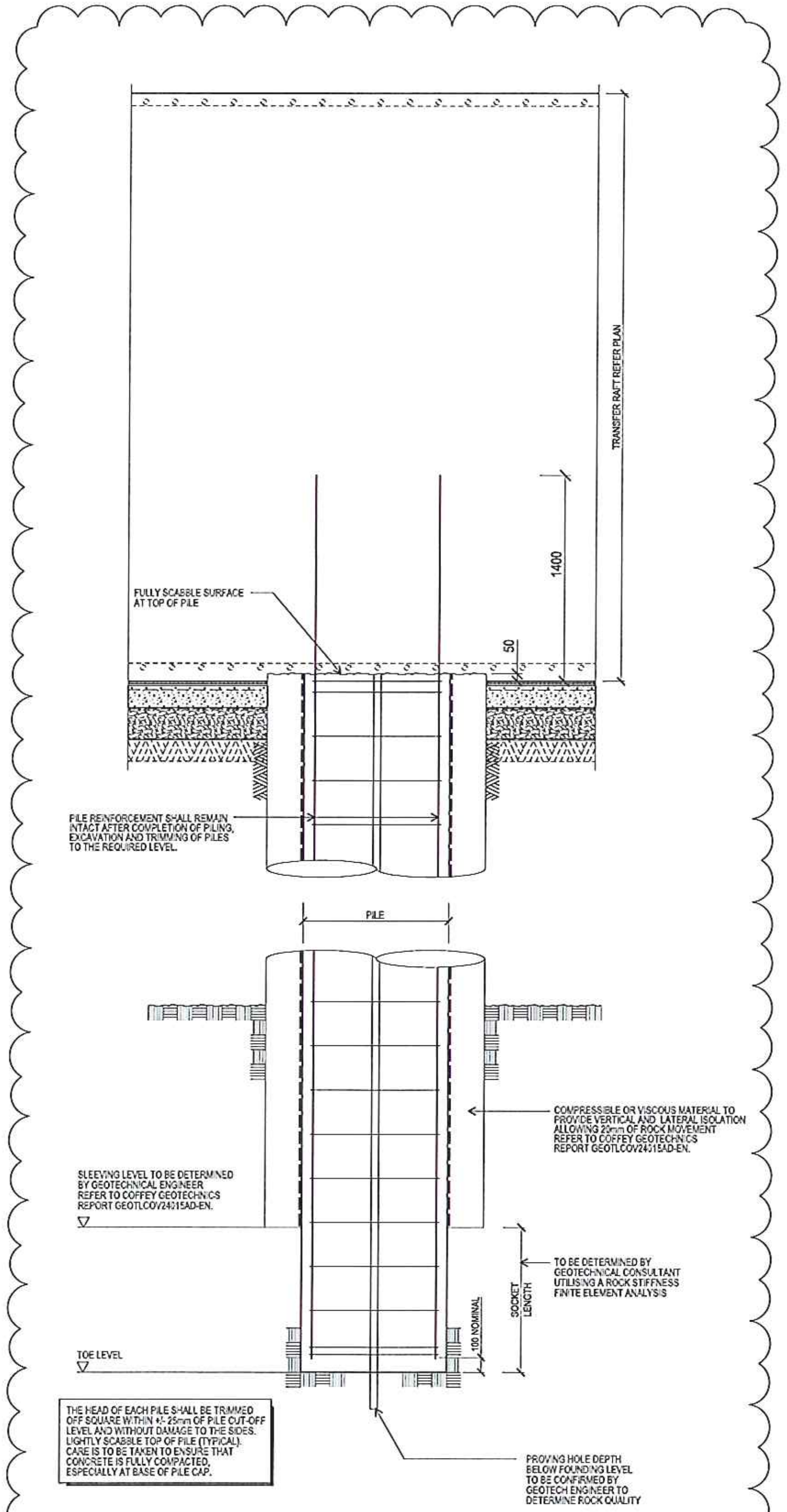
TYPICAL PILE SPLICE - DETAIL

SPLICING SHALL NOT OCCUR WITHIN 6000 FROM PILE CUT OFF

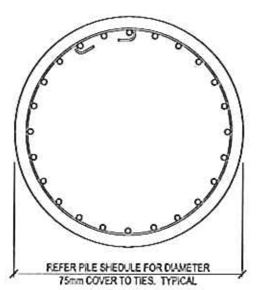


TYPICAL PILE SPLICE - DETAIL
PERMANENT TENSION PILES ONLY

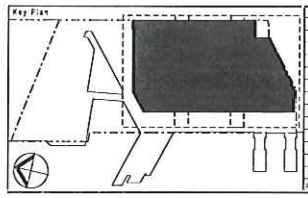
SPLICING SHALL NOT OCCUR WITHIN 6000 FROM PILE CUT OFF



TRANSFER RAFT - PILE SECTION



Key Plan



Rev.	Item	Revision Description	Date
D		ISSUED FOR CONSTRUCTION	04.09.12
	7	DETAIL ADDED	
C		ISSUED FOR CONSTRUCTION	30.04.12
	6	DETAIL ADDED	
B		ISSUED FOR CONSTRUCTION	17.04.12
	5	REINF NOTE REVISED	
A		ISSUED FOR CONSTRUCTION	06.03.12
	4	PILE SECTION AND PLAN REVISED	
	3	PILE SPLICE DETAIL REVISED	
	2	DRAWING RENUMBERED FROM SD1030022	
	1	DETAIL REMOVED, LAYOUT REVISED	
01	-	RE-ISSUED FOR PILE SOCKET DESIGN	12.01.12
00	-	ISSUED FOR PILE SOCKET DESIGN	13.12.11

Rev.	Item	Revision Description	Date
E		ISSUED FOR TRANSPORT FOR NSW APPROVAL	05.10.12

Lead Architects: RSHP — RSHP Australia Pty Ltd, Ivan Harbour | Principal Architect, RAIA NSW ARB 8484, Sydney NSW 2000

Collaborating Architects: Lend Lease — Graham W Jones | Principal Architect, FRAIA NSW ARB 4005, ABN 97 000 098 162

Consultant

Principal: Lend Lease

Developer	Lend Lease
Project Management & Construction	Lend Lease
Design	Lend Lease

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Project: BARANGAROO SOUTH

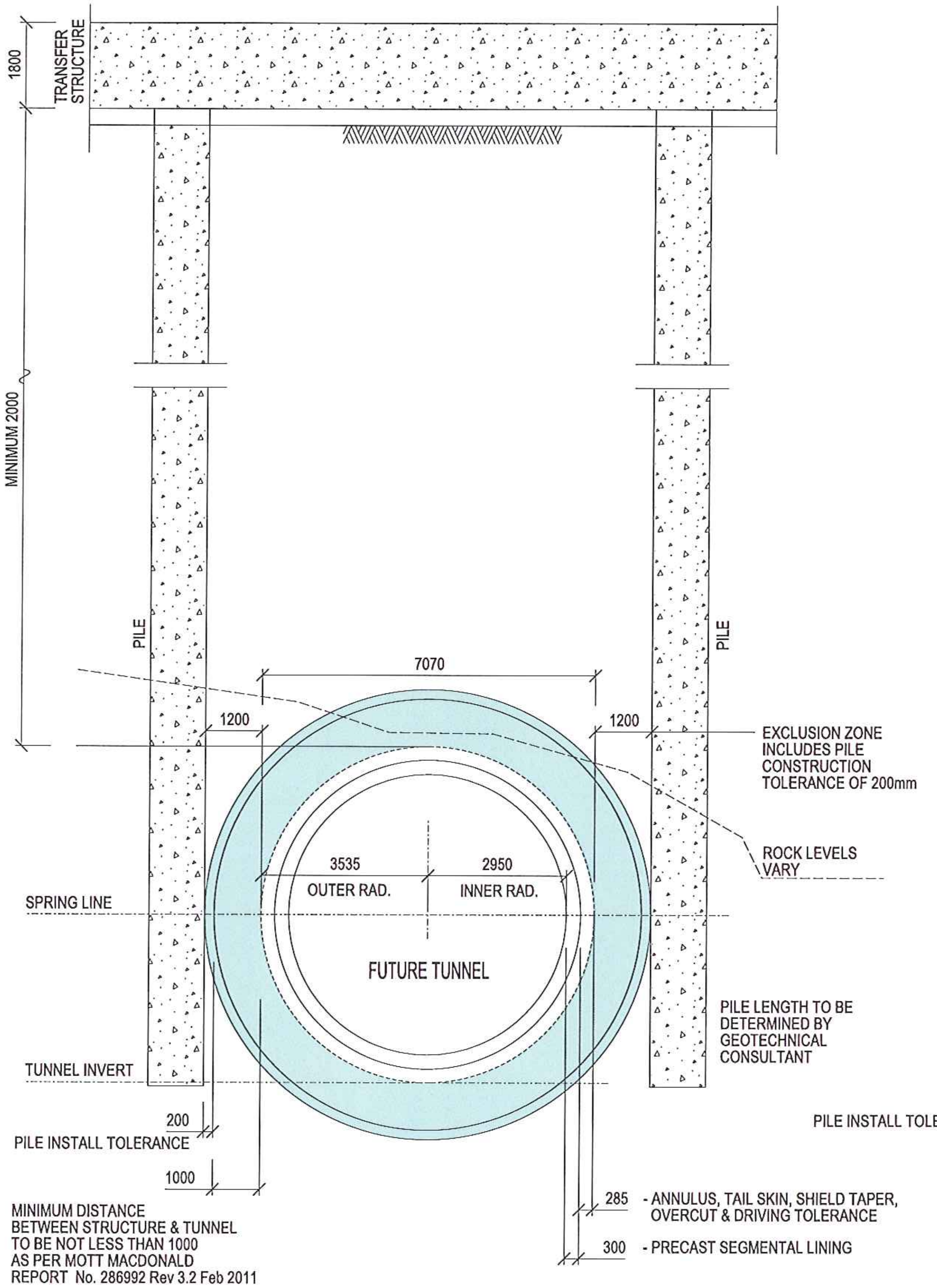
Title: OVERALL SITE PILING DETAILS SHEET 1

Drawn By	Date	Purpose	Approved By	Date
MAM	30/11/11	CONSTN		

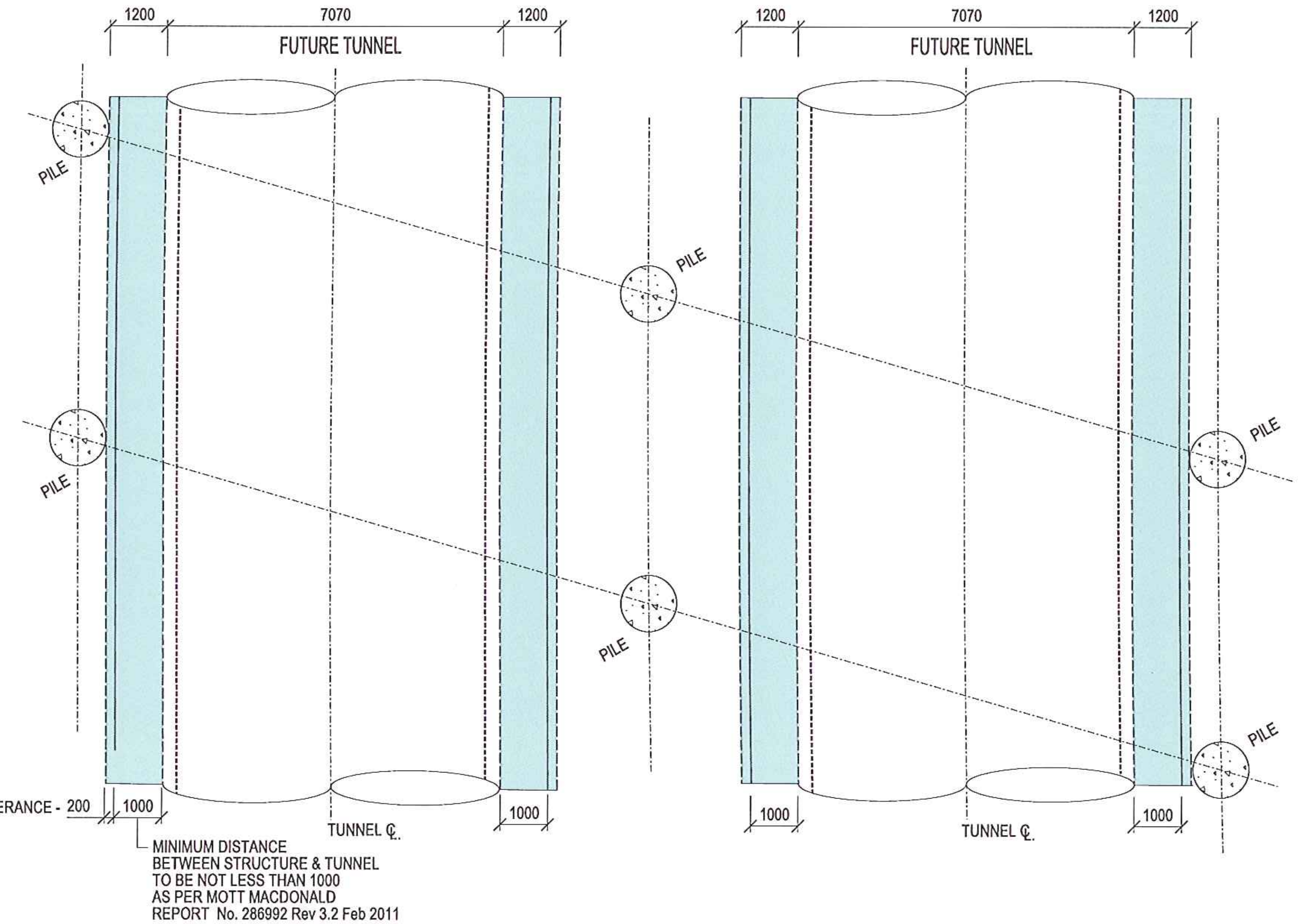
SCALE 1:20 @ B1 — 1:20

Project No.	Site No.	Drawing No.	Revision
161804	BB1	SD1030031	E

B1



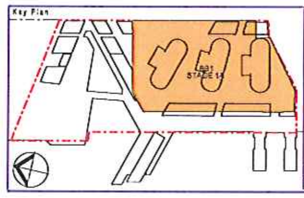
TYPICAL SECTION



TYPICAL PLAN

STRUCTURE SETOUT ADJACENT TO FUTURE METRO TUNNEL

Key Plan



Rev.	Item	Revision Description	Date
00		ISSUED FOR TRANSPORT FOR NSW APPROVAL	05.10.12

B1

Lead Architects: RSHP — RSHP Australia Pty Ltd, Ivan Harbour | Principal Architect, RAIA NSW ARB 8484, Sydney NSW 2000

Collaborating Architects: Lend Lease, Graham W Jones | Principal Architect, FRAIA NSW ARB 4005, ABN 97 000 098 162

Consultant

Principal: Lend Lease

Developer	Lend Lease
Project Management & Construction	Lend Lease
Design	Lend Lease

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Project: BARANGAROO SOUTH

40 51 50

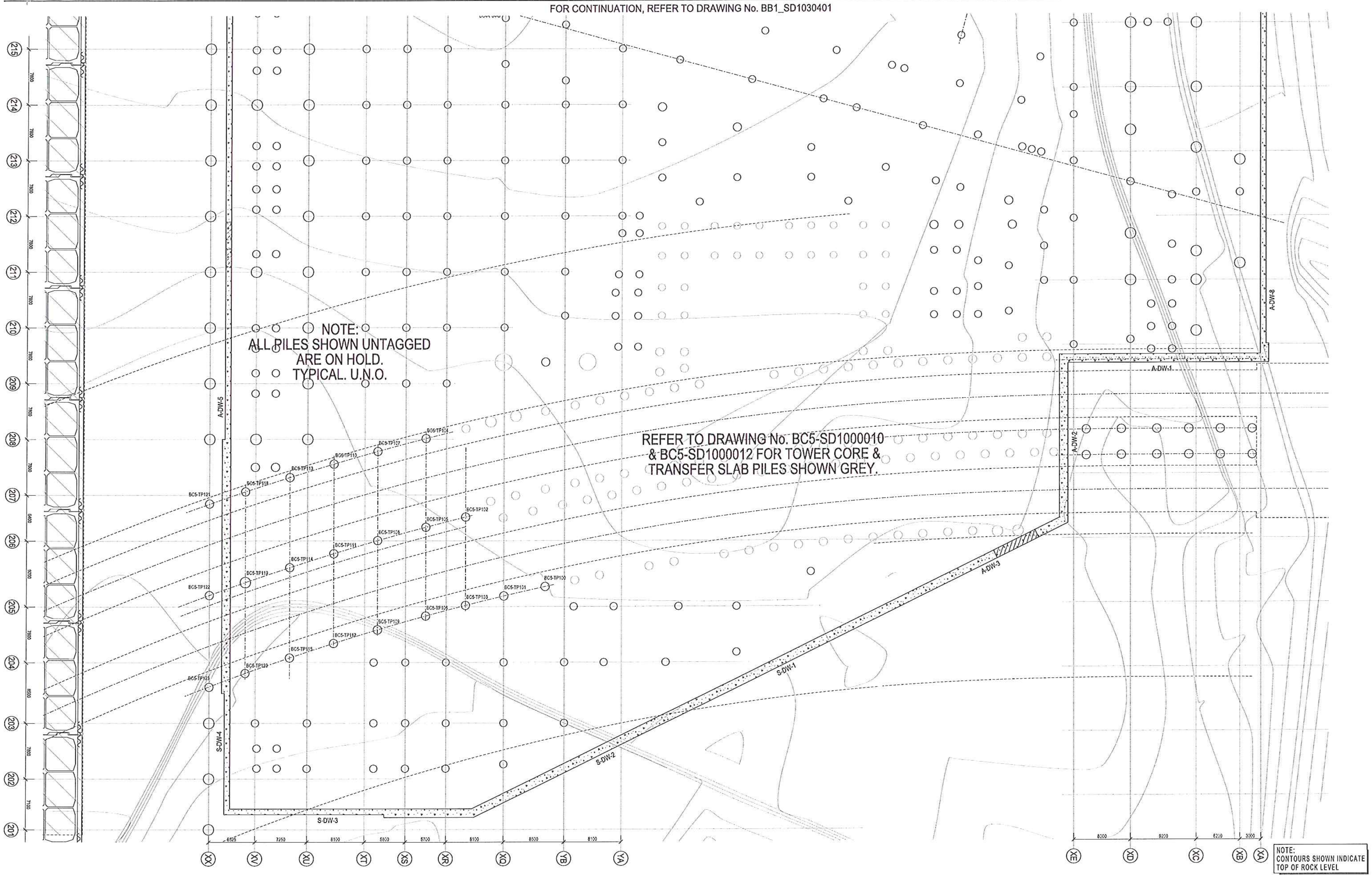
Title: OVERALL SITE PILING DETAILS SHEET 2

Drawn By	Date	Purpose	Approved By	Date
VB	25/09/12	PRELIM		

1:100

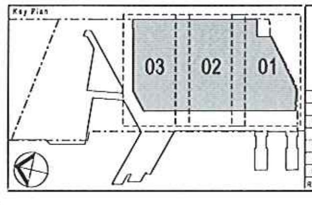
Project No	Site No	Drawing No	Revision
161531	BB1	SD1030032	00

FOR CONTINUATION, REFER TO DRAWING No. BB1_SD1030401



NOTE:
CONTOURS SHOWN INDICATE
TOP OF ROCK LEVEL

Key Plan



Rev.	Item	Revision Description	Date
D		ISSUED FOR TRANSPORT FOR NSW APPROVAL	05.10.12
	2	PILES BC5-TP121 TO BC5-TP123 ADDED	
C	-	ISSUED FOR TRANSFER PILE SOCKET DESIGN	04.09.12
	1	TRANSFER PILES ADDED	
B		ISSUED FOR PILING CONSTRUCTION CERTIFICATE	14.06.12
A	-	ISSUED FOR CONSTRUCTION	05.06.12
00	-	ISSUED FOR PILE SOCKET DESIGN	17.04.12

Rev.	Item	Revision Description	Date

B1

Lead Architects
RSHP
RSHP Australia Pty Ltd
Ivan Harbour | Principal Architect
RAIA NSW ARB 8414
Sydney NSW 2000

Collaborating Architects
Lend Lease
Graham W Jones | Principal Architect
FRAIA NSW ARB 4005
ABN 97 000 098 162

Consultant

Principal
Lend Lease

Developer	Lend Lease
Project Management & Construction	Lend Lease
Design	Lend Lease

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Millers Point NSW 2000
www.lendlease.com

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Project
BARANGAROO SOUTH

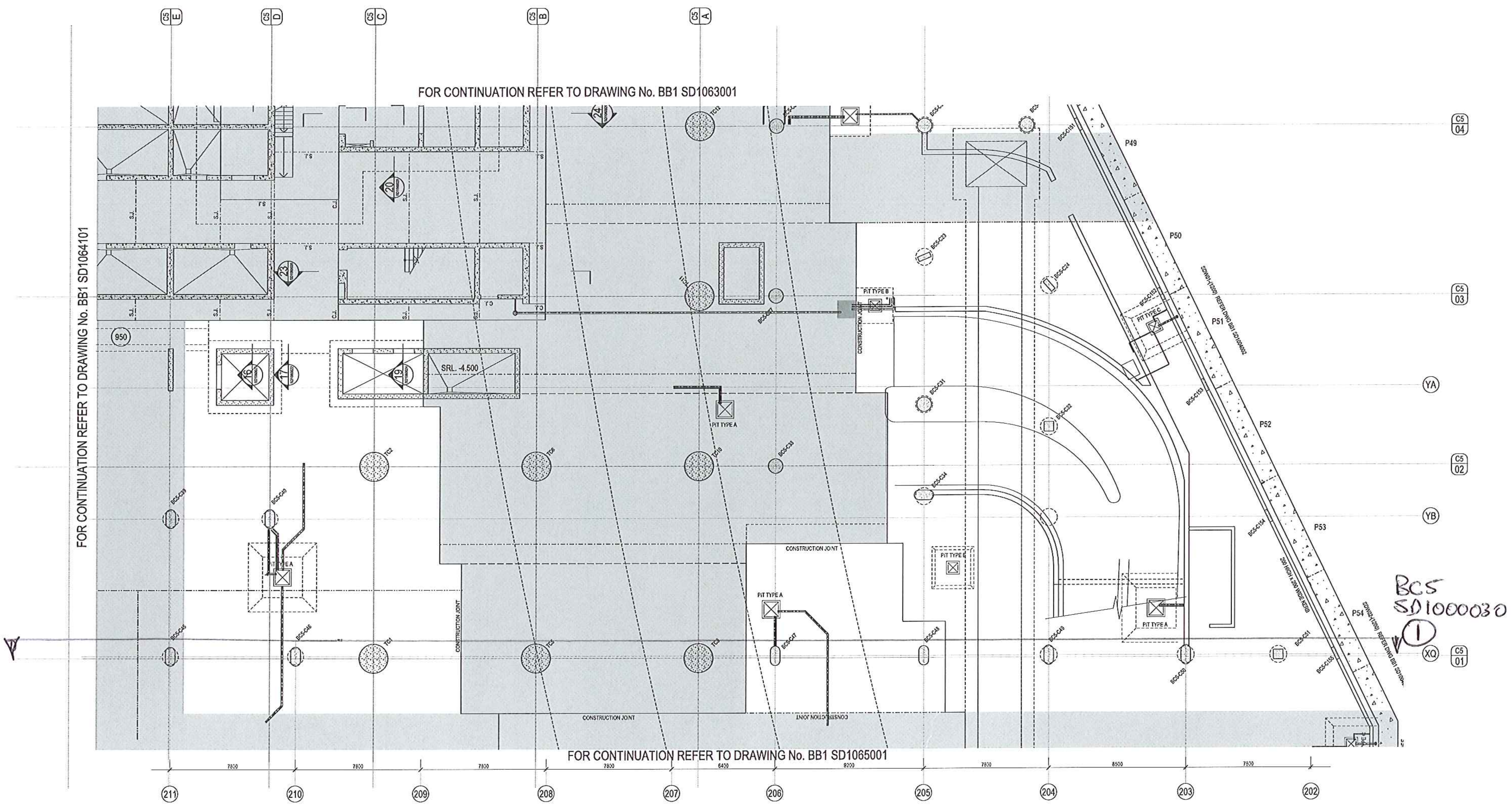
03
02
01

Title
OVERALL C5 PILE LAYOUT PLAN ZONE 01

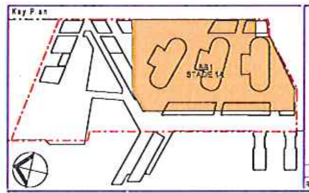
Drawn By	Date	Purpose	Approved By	Date
MAM	08/12/11	CONSTN		

0 5 10 15 M
SCALE 1:200 @ B1

Project No	Site No	Drawing No	Revision
161804	BB1	SD1030301	D



Rev.	Item	Revision Description	Date
00		ISSUED FOR INFORMATION	03.10.12



NOTES:

1. SSL ON PLAN DENOTES STRUCTURAL SLAB LEVEL
2. FOR CORE WALLS ELEVATIONS - REFER TO DRAWINGS
3. (200) INDICATES VARIATION IN SLAB THICKNESS

ABRIDGED NOTES

REFER TO DRAWING No. TBC FOR NOTES

A1. Concrete Quality

ELEMENT	STRENGTH GRADE (MPa)	MAXIMUM AGGREGATE Size (mm)	SPECIFIED SLUMP (mm)
SLABS & BANDS	50	20	60
WALLS	VARY	20	60

A2. Provide the following clear cover to all reinforcement unless noted otherwise on the drawings.

ELEMENT	CAST AGAINST FORMS COMPLYING WITH AS 3610		CAST AGAINST OTHER FORMWORK OR ON THE GROUND
	IN SHELTERED LOCATIONS	EXPOSED TO GROUND WATER OR WEATHER	
SLABS	30	40	75
WALLS	30	40	75

LOADINGS

CARPARK

LIVE LOAD 3.0 kPa
KERBS AND FALLS 1.0 kPa
SERVICES UNDER 0.5 kPa

PLANT

LIVE LOAD 7.5 kPa
PLINTHS AND FALLS 2.5 kPa
SERVICES UNDER 0.5 kPa

Lead Architects: RSHP — RSHP Australia Pty Ltd, Ivan Harbour | Principal Architect, RAIA NSW ARB 8484, Sydney NSW 2000

Collaborating Architects: Lend Lease — Graham W Jones | Principal Architect, FRAIA NSW ARB 4005, ABN 97 000 098 162

Consultant:

Principal: Lend Lease

Developer	Lend Lease
Project Management & Construction	Lend Lease
Design	Lend Lease

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Project: BARANGAROO SOUTH

30 41 40 50

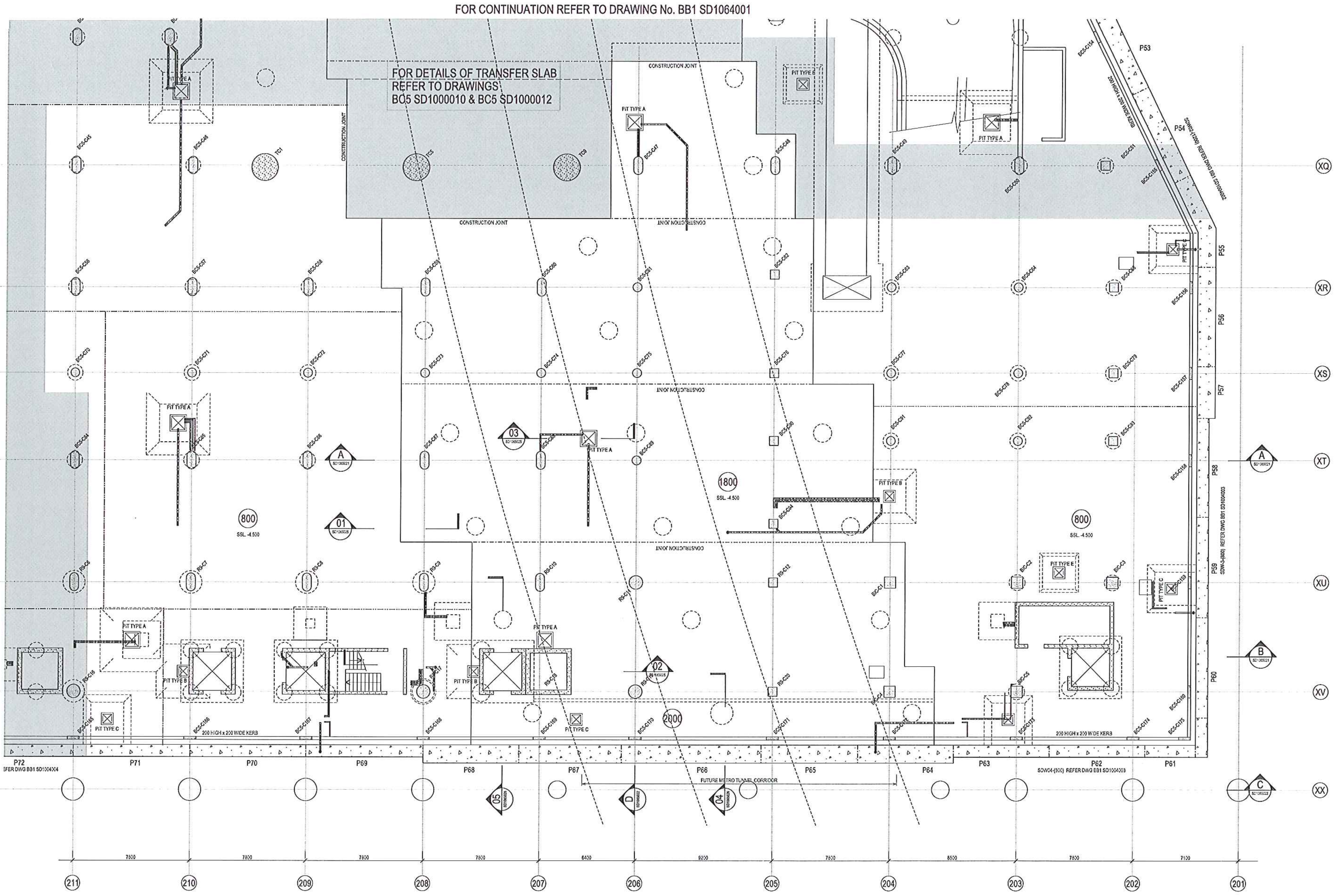
Title: BASEMENT B2 SUBZONE 40 CONCRETE OUTLINE

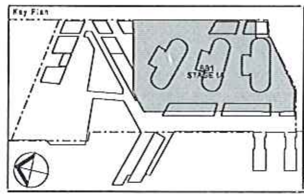
Drawn By	Date	Purpose	Approved By	Date
BH	03/10/12	FOR INFO		

SCALE 1:100 @ B1 — 0 — 5M — 1:100

Project No.	Site No. Drawing No.	Revision
161804	BB1 SD1064001	00

B1





Rev.	Item	Revision Description	Date
01		ISSUED FOR TRANSPORT FOR NSW APPROVAL	05.10.12
00		ISSUED FOR INFORMATION	03.10.12

NOTES:

1. SSL. ON PLAN DENOTES STRUCTURAL SLAB LEVEL
2. FOR CORE WALLS ELEVATIONS - REFER TO DRAWINGS
3. (200) INDICATES VARIATION IN SLAB THICKNESS

ABRIDGED NOTES

REFER TO DRAWING No. TBC FOR NOTES

A1. Concrete Quality

ELEMENT	STRENGTH GRADE (MPa)	MAXIMUM AGGREGATE Size (mm)	SPECIFIED SLUMP (mm)
SLABS & BANDS	50	20	60
WALLS	VARY	20	60

A2. Provide the following clear cover to all reinforcement unless noted otherwise on the drawings.

ELEMENT	CAST AGAINST FORMS COMPLYING WITH AS 3610		CAST AGAINST OTHER FORMWORK OR ON THE GROUND
	IN SHELTERED LOCATIONS	EXPOSED TO GROUND WATER OR WEATHER	
SLABS	30	40	75
WALLS	30	40	75

LOADINGS

CARPARK

LIVE LOAD	3.0 kPa
KERBS AND FALLS	1.0 kPa
SERVICES UNDER	0.5 kPa

PLANT

LIVE LOAD	7.5 kPa
PLINTHS AND FALLS	2.5 kPa
SERVICES UNDER	0.5 kPa

Lead Architects: RSHP — RSHP Australia Pty Ltd, Ivan Harbour | Principal Architect, RAIA NSW ARB 8484, Sydney NSW 2000

Collaborating Architects: Lend Lease, Graham W Jones | Principal Architect, FRAIA NSW ARB 4005, ABN 97 000 098 162

Consultant

Principal: Lend Lease

Developer	Lend Lease
Project Management & Construction	Lend Lease
Design	Lend Lease

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Project: BARANGAROO SOUTH

40 51 50

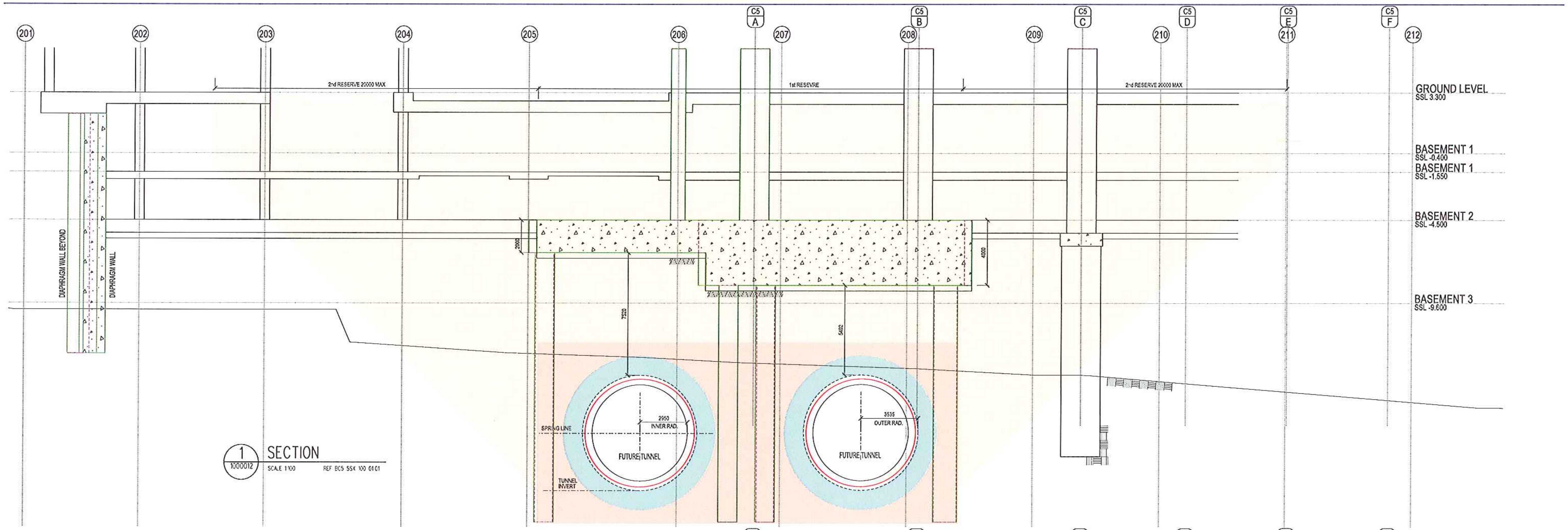
Title: BASEMENT B2 SUBZONE 50 CONCRETE OUTLINE

Drawn By	Date	Purpose	Approved By	Date
BH	03/10/12	FOR INFO		

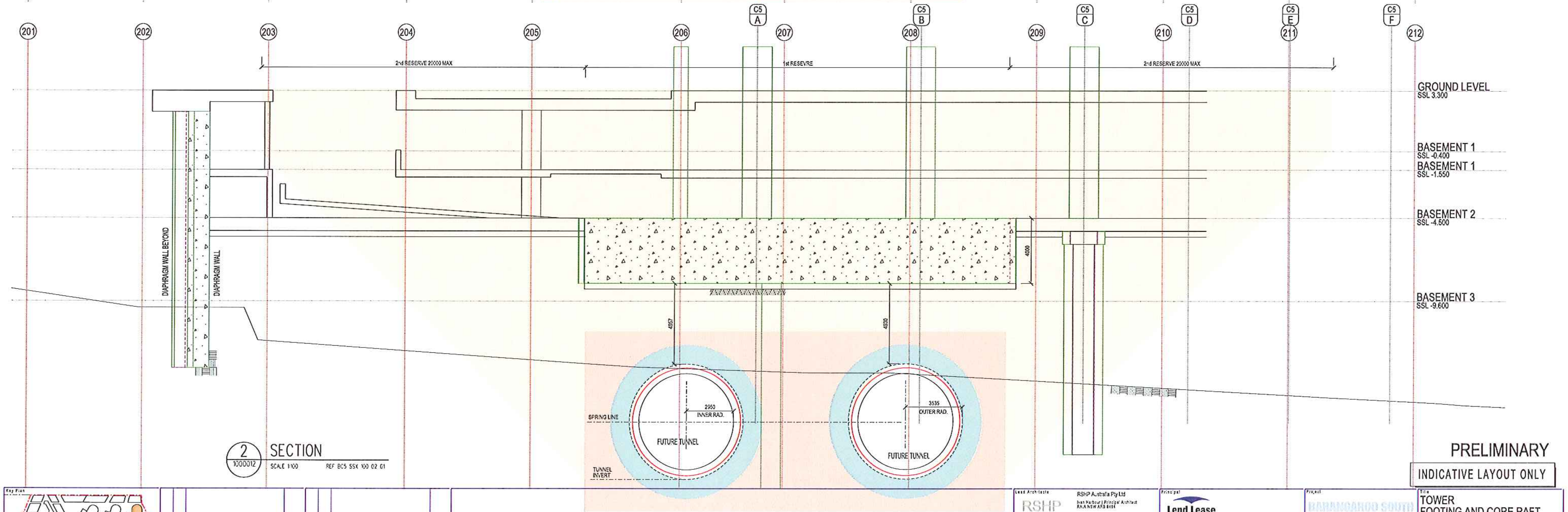
SCALE 1:100 @ B1 1:100

Project No	Site No	Drawing No	Revision
161804	BB1	SD1065001	01

B1



1 SECTION
1000012
SCALE 1:100 REF BC5 SSK 100 01 01



2 SECTION
1000012
SCALE 1:100 REF BC5 SSK 100 02 01

PRELIMINARY

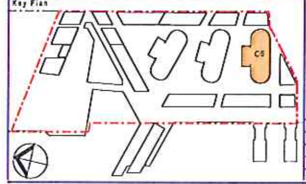
INDICATIVE LAYOUT ONLY

SYDNEY METRO ZONE OF INFLUENCE

SYDNEY METRO PROTECTION ZONE

EXCLUSION ZONE FOR STRUCTURAL ELEMENTS

Key Plan



Rev.	Item	Revision Description	Date
03	-	ISSUED FOR INFORMATION	02.03.12
02	-	ISSUED FOR INFORMATION	31.10.11
01	-	ISSUED FOR INFORMATION	20.07.11
00	-	ISSUED FOR INFORMATION	29.06.11

Rev.	Item	Revision Description	Date

Lead Architects: RSHP — RSHP Australia Pty Ltd, Ivan Harbour | Principal Architect, RAIA NSW ARB 8484, Sydney NSW 2000

Collaborating Architects: Lend Lease, Graham W Jones | Principal Architect, FRAIA NSW ARB 4005, ABN 97 000 098 162

Consultant

Principal: Lend Lease

Developer	Lend Lease
Project Management & Construction	Lend Lease
Design	Lend Lease

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Project: BARANGAROO SOUTH

C5

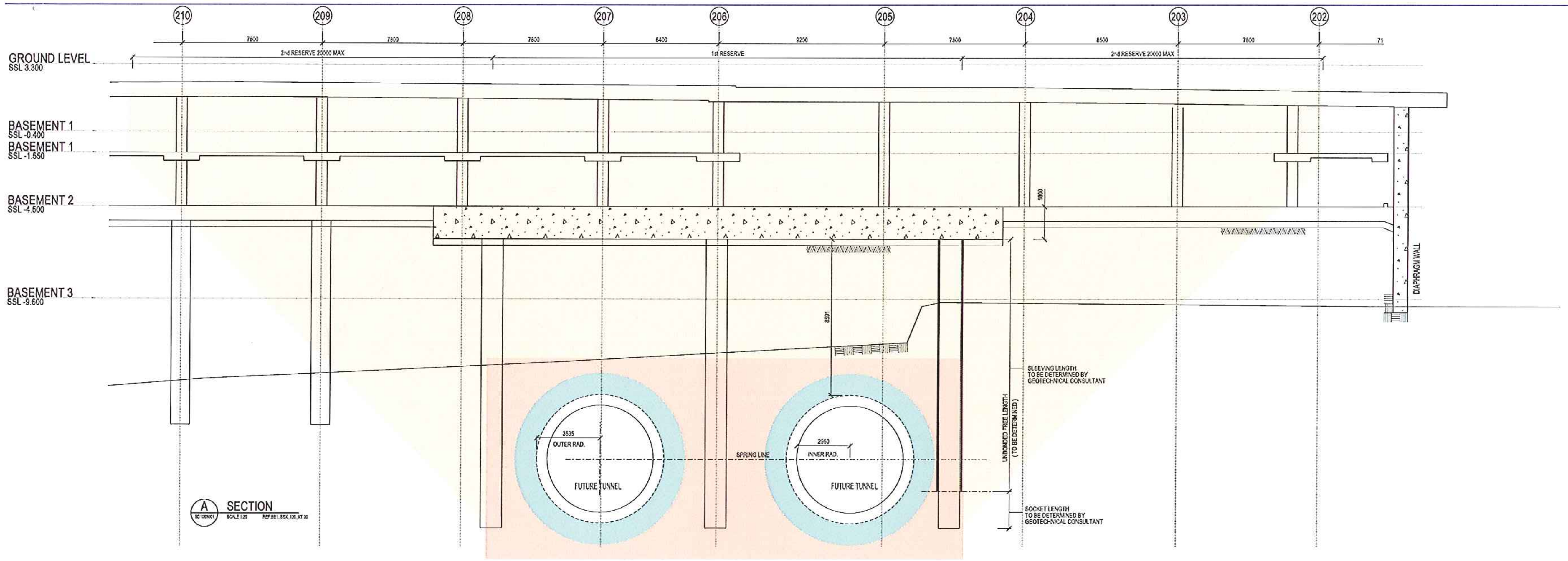
Title: TOWER FOOTING AND CORE RAFT SECTIONS SHEET 1

Drawn By	Date	Purpose	Approved By	Date
BH	24.10.11	PRELIM		

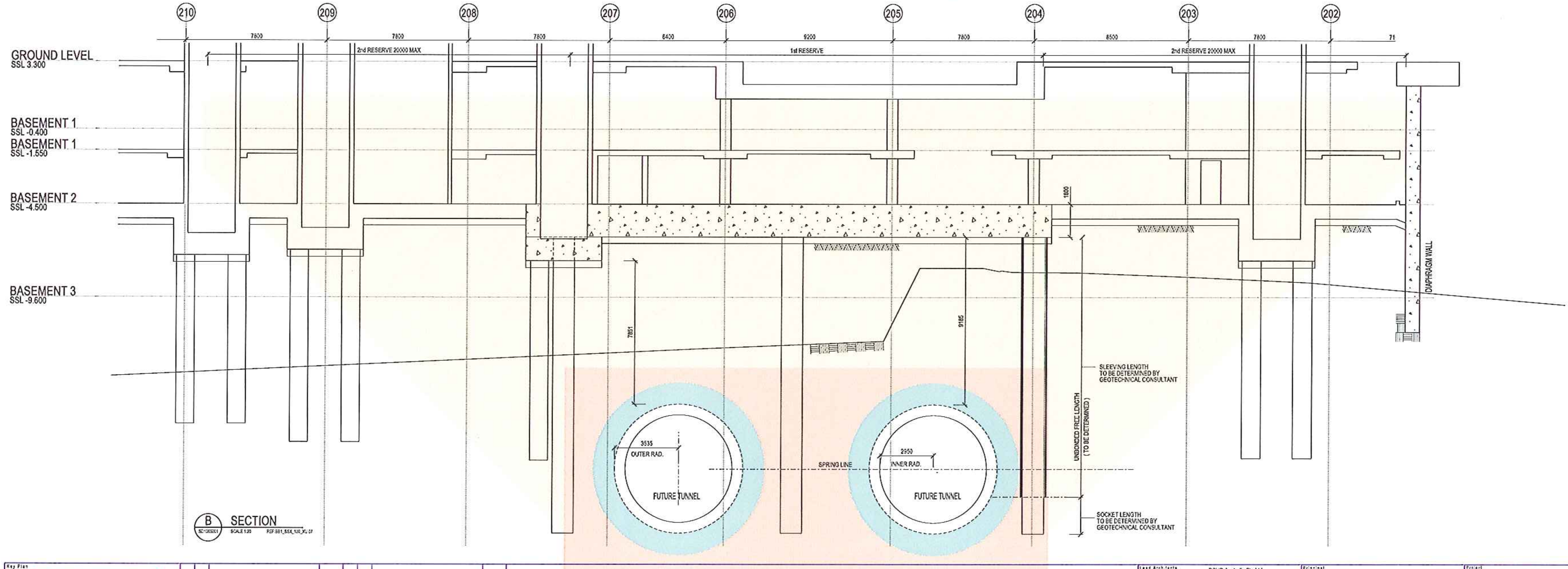
SCALE 1:100 @ B1 1:250 @ A3 — 1:100

Project No	Site No Drawing No	Revision
161531	BC5 SD1000030	03

B1

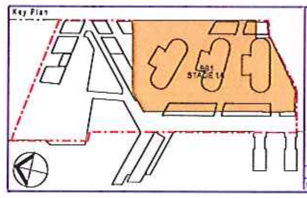


A SECTION
SCALE 1:20



B SECTION
SD1065001 SCALE 1:20 REF:BB1_SSX_100_XU 07

Key Plan



Rev.	Item	Revision Description	Date	Rev.	Item	Revision Description	Date
00		ISSUED FOR TRANSPORT FOR NSW APPROVAL	05.10.12				

SYDNEY METRO ZONE OF INFLUENCE

SYDNEY METRO PROTECTION ZONE

EXCLUSION ZONE FOR STRUCTURAL ELEMENTS

Lead Architects: RSHP Australia Pty Ltd, Ivan Harbour | Principal Architect, RAIA NSW ARB 8484, Sydney NSW 2000

Collaborating Architects: Lend Lease, Graham W Jones | Principal Architect, FRAIA NSW ARB 4005, ABN 97 000 098 162

Consultant

Principal: Lend Lease

Developer	Lend Lease
Project Management & Construction	Lend Lease
Design	Lend Lease

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Project: BARANGAROO SOUTH

40
51 50

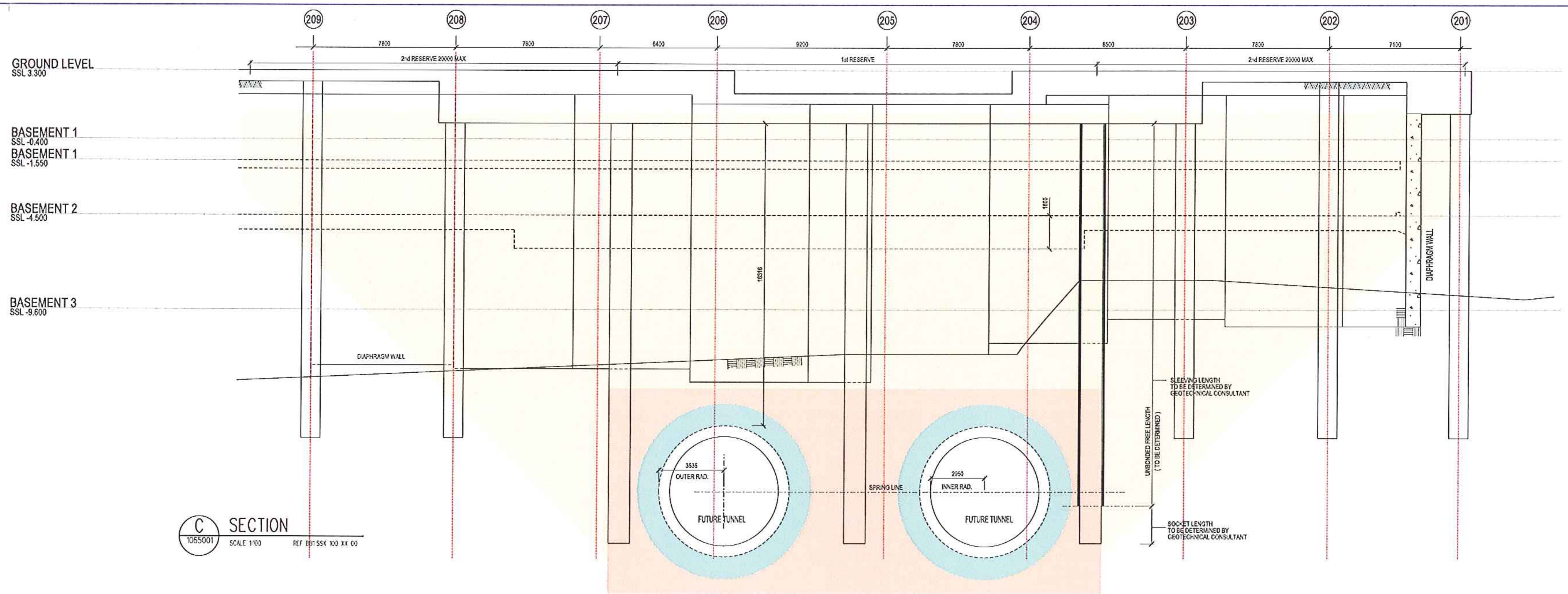
Title: BASEMENT B2 SUBZONE 50 - TRANSFER SECTIONS SHEET 1

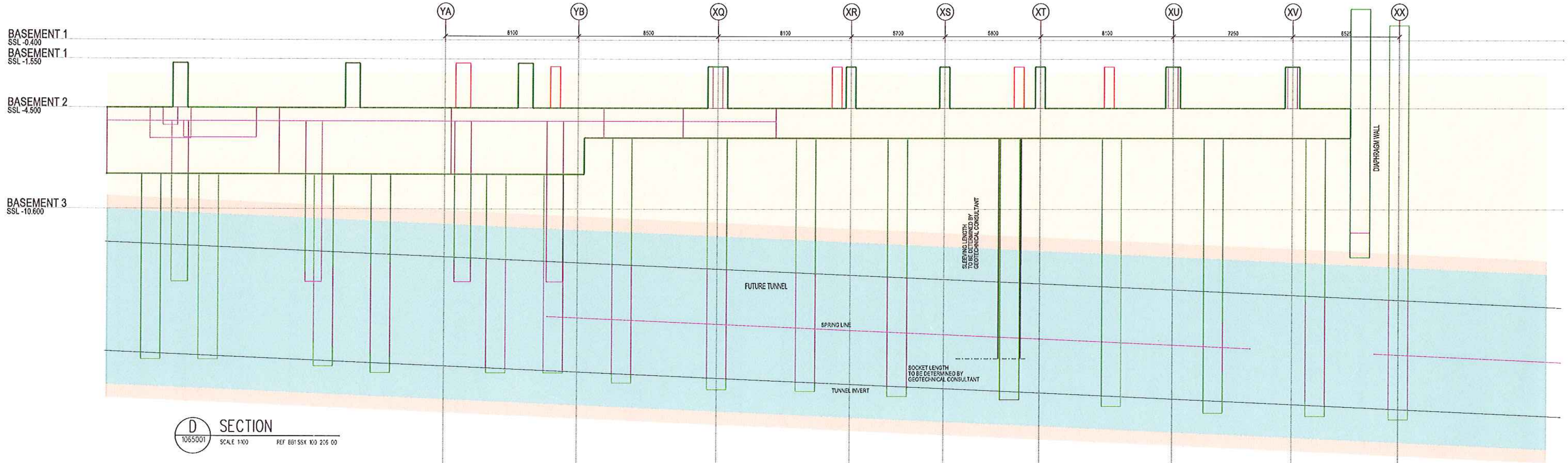
Drawn By	Date	Purpose	Approved By	Date
BH	21/08/12	FOR INFO		

SCALE 1:20 @ B1 1:100

Project No.	Site No.	Drawing No.	Revision
161804	BB1	SD1065021	00

B1





SYDNEY METRO ZONE OF INFLUENCE

SYDNEY METRO PROTECTION ZONE

EXCLUSION ZONE FOR STRUCTURAL ELEMENTS

Lead Architects	RSHP Australia Pty Ltd, Ivan Harbour / Principal Architect, RAIA NSW ARB 8484, Sydney NSW 2000
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Principal	Lend Lease
Developer	Lend Lease
Project Management & Construction	Lend Lease
Design	Lend Lease
Project	BARANGAROO SOUTH
Title	BASEMENT B2 SUBZONE 50 - TRANSFER SECTIONS SHEET 2
Drawn By	BH
Date	21/08/12
Purpose	FOR INFO
Scale	SCALE 1:20 @ B1 1:100
Project No.	161804
Site No.	BB1
Drawing No.	SD1065022
Revision	00

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Rev.	Item	Revision Description	Date
00		ISSUED FOR TRANSPORT FOR NSW APPROVAL	06.12.12

B1

Appendix D

Geological Profiles – Barangaroo South

BARANGAROO SOUTH.

R8 & R9 Residential Buildings
Planning Application - 11_0002

ARCHITECTURAL DRAWINGS:

BB1_PA_R8R9_A000 - TITLE SHEET
BB1_PA_R8R9_A101 - BASEMENT PLAN LEVEL B1
BB1_PA_R8R9_A102 - BASEMENT PLAN LEVEL B2
BB1_PA_R8R9_A201 - CROSS SECTION 1-1
BB1_PA_R8R9_A202 - LONGITUDINAL SECTION 2-2

INDICATIVE LAYOUT ONLY

LEGEND:

- DECCW DECLARATION AREA
- PROPERTY BOUNDARY
- APPROXIMATE EXTENT OF RESIDENTIAL BUILDING FOOTPRINT ABOVE
- EXTENT OF RESIDENTIAL AND COMMON BASEMENT FACILITIES
- RESIDENTIAL CAR PARK SPACES
- RETAIL CAR PARK SPACES
- HARBOUR HEAT REJECTION ZONE

INDICATIVE LAYOUT ONLY

Lend Lease design

GRAHAM W JONES
Principal Architect
FRAIA NSW ARB 4005

Lend Lease (Millers Point) Pty Limited

BARANGAROO
STAGE 1

R8 & R9 Residential Buildings
Planning Application - 11_0002
Basement Level 1

Purpose:	Approved:	Date:
DESIGN	GRAHAM JONES	09/10/12

Scale 1:500 @ B1 NTS @ A3

0 25 50M

Drawing No. BB1_PA_R8R9_A101
Issue 03 Date 18/10/12

LEGEND:

- DECCW DECLARATION AREA
- PROPERTY BOUNDARY
- APPROXIMATE EXTENT OF RESIDENTIAL BUILDING FOOTPRINT ABOVE
- EXTENT OF RESIDENTIAL AND COMMON BASEMENT FACILITIES
- RESIDENTIAL CAR PARK SPACES
- RETAIL CAR PARK SPACES
- HARBOUR HEAT REJECTION ZONE

INDICATIVE LAYOUT ONLY

Lend Lease design

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Lend Lease (Millers Point) Pty Limited

BARANGAROO
STAGE 1

R8 & R9 Residential Buildings
Planning Application - 11_0002
Basement Level 2

Purpose:	Approved:	Date:
DESIGN	GRAHAM JONES	09/10/12

Scale 1:500 @ B1 NTS @ A3

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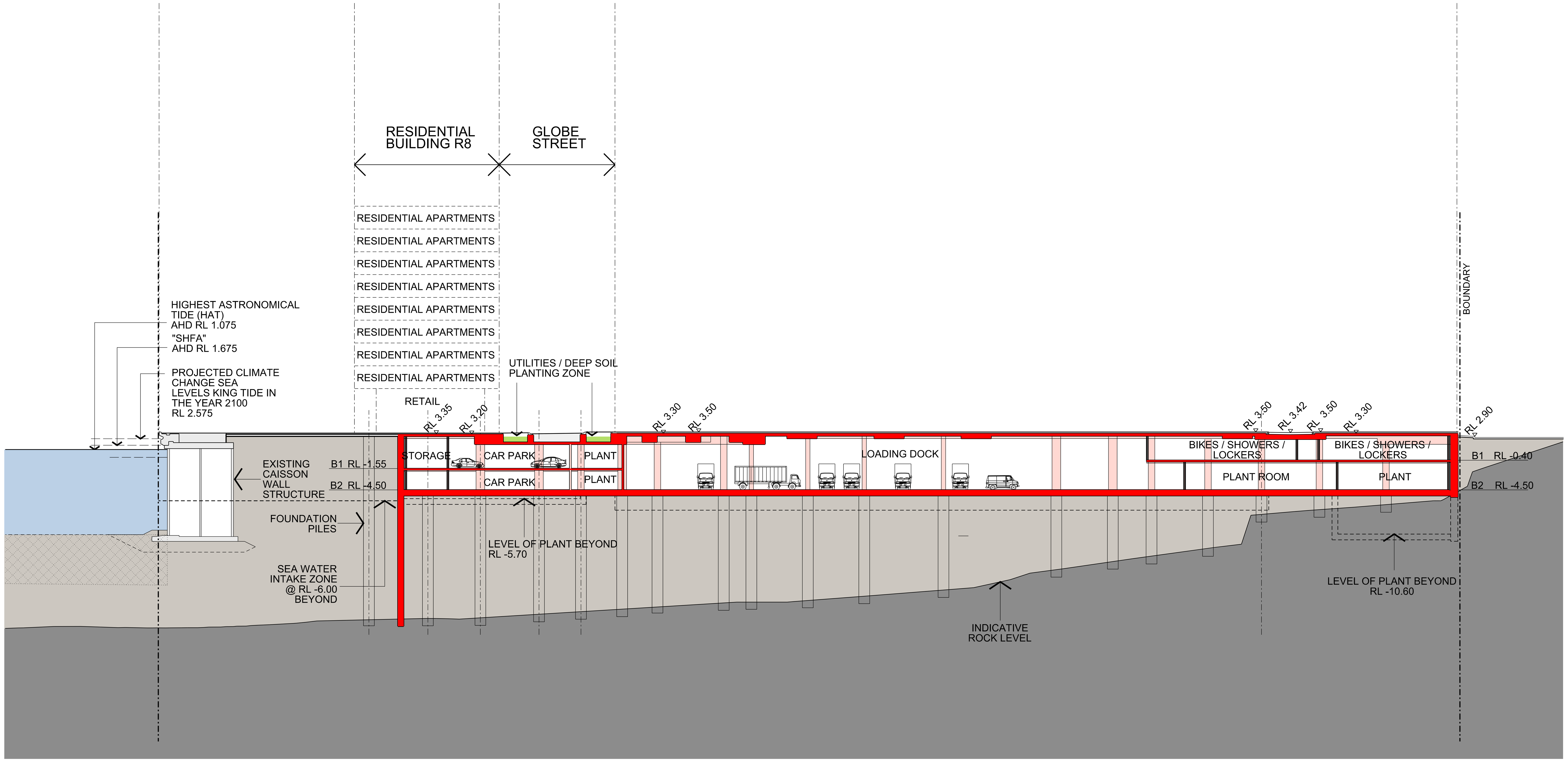
Drawing No. BB1_PA_R8R9_A102

Issue 03 Date 18/10/12



CROSS SECTION 1-1

INDICATIVE LAYOUT ONLY

Lend Lease design

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Lend Lease (Millers Point) Pty Limited

BARANGAROO
STAGE 1

R8 & R9 Residential Buildings
Planning Application - 11_0002
Cross Section 1-1

Purpose: DESIGN | Approved: GRAHAM JONES | Date: 09/10/12

Scale 1:300 @ B1 NTS @ A3

0 7.5 15 22.5 30M

Drawing No. BB1_PA_R8R9_A201
Issue 02 Date 17/10/12

LONGITUDINAL SECTION 2-2

INDICATIVE LAYOUT ONLY

Lend Lease design

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FRAIA NSW ARB 4005

Lend Lease (Millers Point) Pty Limited

BARANGAROO
STAGE 1

R8 & R9 Residential Buildings
Planning Application - 11_0002
Longitudinal Section 2-2

Purpose:	Approved:	Date:
DESIGN	GRAHAM JONES	09/10/12

Scale 1:300 @ B1 NTS @ A3

0 7.5 15 22.5 30M

Drawing No. BB1_PA_R8R9_A202
Issue 02 Date 17/10/12

Appendix E

Relevant Technical Papers

The Soft Ground Bored Tunnel Under Sydney Airport

E J Nye[1]

INTRODUCTION

The New Southern Railway (NSR) involves the excavation of approximately 10 km of single bore tunnel from Tempe Reserve, Tempe, to Prince Alfred Park (PAP). PAP is located just south of Central Railway Station in Sydney's Central Business District (CBD). From Tempe Reserve the alignment takes the tunnel under Sydney Airport including the main north/south runway. Sydney Airport is approximately 8 km south of the CBD.

The NSR is being constructed by a private group, the Transfield Bouygues Joint Venture (TBJV). Transfield is a major Australian contractor and the French contractor, Bouygues, is providing the soft ground tunnel construction expertise and is also responsible for the design of the concrete segmental lining.

Approximately 6 km of the 10 km tunnel is in soft ground (clays and sands) and is currently being excavated by a 10.7 m external diameter Herrenknecht slurry Tunnel Boring Machine(TBM). The soft ground tunnel, which was excavated by the TBM under Federal Airport Corporation (FAC) land is now complete (the FAC is now the Sydney Airport Corporation). The TBM is currently advancing towards the TBM exit shaft (TBMX) to the north of Mascot Station. Final breakthrough to the TBMX will be in June 1999 and will herald the completion of tunnelling on the project.

Two underground railway stations are located on FAC land at Sydney Airport. One station is at the International Terminal and the other at the Domestic Terminal. The two stations are connected by the tunnel which passes under the main north/south runway. Figure 1 shows the horizontal alignment of the tunnel between these two stations.

This paper sets out to present in some detail the issues involved in tunnelling under the airport and in particular under the north apron, the main north/south runway and the new elevated roadway. The paper concentrates on these three areas on the airport with an emphasis on the following. The risks involved and measures taken to minimise the risks in tunnelling under the International Terminal north apron (with Jumbo Jets parked immediately above). Secondly, settlement predictions, settlement and runway operation criteria and the actual settlements that have occurred on the main north/south runway. Finally, the criteria that was developed during the construction of the deep bored piers for the elevated roadway at the Domestic Terminal as the TBM passed through this area of construction activity.

1. Director, E J Nye and Associates Pty Ltd, PO Box 621, North Sydney NSW 2059.

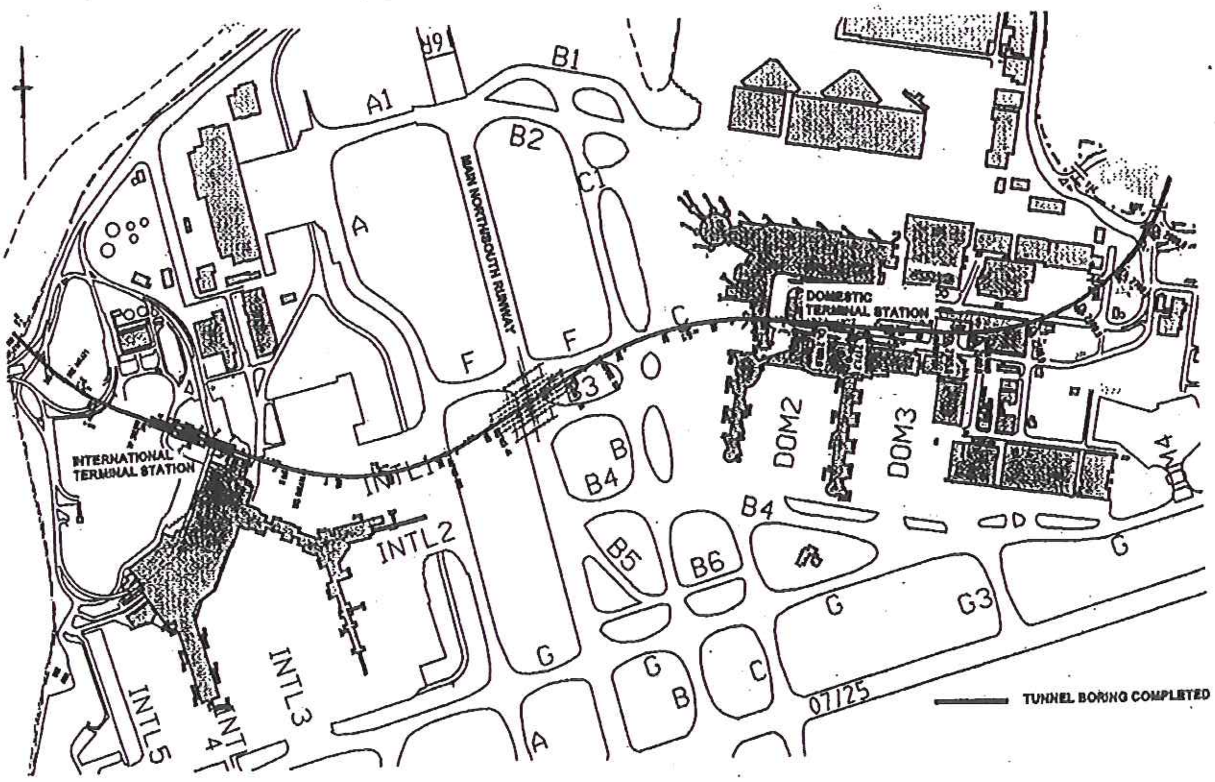

Fig 1 - Plan of Sydney airport with tunnel alignment.

RESPONSIBILITIES OF THE VARIOUS STAKEHOLDERS

The NSR is being constructed by the TBJV on behalf of the State Rail Authority of NSW (now the responsibility of the Rail Access Corporation (RAC)). A contract between the SRA and the TBJV was negotiated and a separate agreement exists between the FAC and the SRA. There is no direct contract between the TBJV and the FAC. Under the terms of the agreements the project was required to take the necessary measures to minimise the probability of any physical damage and have in place contingency procedures to minimise the consequences of any damage which occurred. The project is being project managed on behalf of the RAC by Kinhill Engineers Pty Ltd. The author is a consultant and the project design reviewer for the NSR within Kinhill's project management team. The author was commissioned separately by RAC to produce several reports related to tunnelling under the airport on airside. This paper draws heavily on the contents of these reports and on the criteria and procedures developed by the TBJV.

THE TUNNEL LINING AND THE TBM

The tunnel lining is precast concrete segments which are erected in the tail of the TBM as the TBM advances through the ground. The lining is 450 mm thick and approximately 1.8 m wide and consists of seven individual segments and a key segment. Each segment ring is tapered so that the circumferential joints are flush with each other even around curves in the tunnel alignment. The performance criteria for the lining is that there are no drips or flowing water over the inside tunnel concrete surface of the lining. This has been achieved in construction by the lining design incorporating rubber gaskets and hydrophilic strips to seal the joints against outside water pressure together with very tight tolerances on the manufacture and erection of the concrete segments. Apart from minimising the potential for future maintenance problems in the tunnel, a watertight tunnel lining does not effect the groundwater table level in either the short or long-term. Consequently there are no groundwater table level related settlement issues compared to other tunnels that do not have a watertight lining.

The TBM is of the slurry type. A treatment plant at the surface supplies the bentonite clay and also recycles the clay after removing sand particles. The bentonite slurry fills a sealed chamber at the front of the TBM and supports the soft ground by providing a pressure at the tunnel face equal to or greater than the external ground and water pressure. Entry to the TBM chamber (an intervention) to carryout maintenance and repairs, eg to replace disc cutters and spades, is obtained after displacing the bentonite slurry with compressed air. Workmen enter the chamber via airlocks. During tunnelling an intervention presents the greatest risk to disturbing the ground above the tunnel.

The ground behind the TBM is supported by concrete tunnel lining segments. These segments are erected in the tail of the TBM shield. The annulus between the concrete segments and the excavated ground at the tail of the TBM is continuously filled by pressure grout injection. The pressure of injection of this grout is at least equal to the face slurry pressure and generally greater. Although it is important to maintain face pressure the grout injected into the lining annulus is critical to minimising surface settlement.

Extensive three-dimensional modelling has been carried out (Swoboda and Mansour, 1996) to demonstrate the sensitivity of surface settlement to variations in both the slurry pressure at the face of the tunnel and the grout pressure in the annulus behind the concrete segments. In a slurry TBM there can be a physical connection between the face slurry and the tail grout, thus both pressures can be maintained continuously. This is the major advantage of slurry TBM technology over current Earth Pressure Balance (EPB) technology. This attribute allows slurry TBMs to reduce surface settlement below that obtained by EPB TBMs in similar ground conditions. Two graphs from Reference 1 have been reproduced in Figures 2a and 2b. The surface settlement results plotted on these two graphs demonstrate that varying the face pressure has little effect on the final settlement (Figure 2a, provided face stability is maintained). However, varying the tail grout pressure can result in significant variations in the final surface settlement (Figure 2b). The theoretical studies were for a 9.6 m diameter tunnel with 12 m of ground cover to the tunnel crown. Other parameters were a unit weight of soil of 20 KN/m^3, a Modulus of Elasticity of soil of 60 MPa and a Poisson's Ratio 0.3 and K_0 equal to 0.6. The TBJV had to consider both slurry and EPB technology when selecting the TBM. The major influencing factor was the concern to minimise settlements under the airport and this was the reason why a slurry TBM was chosen for the project and not an EPB TBM. On a slurry TBM both the face pressure and the tail grout pressure can be accurately controlled.

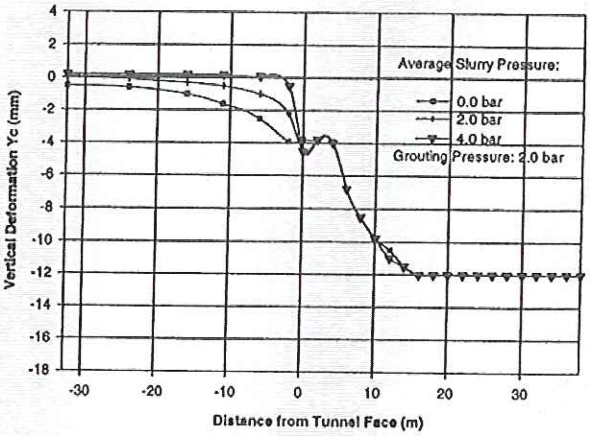

FIG 2a - Vertical deformation along crown for different values of average slurry pressure.

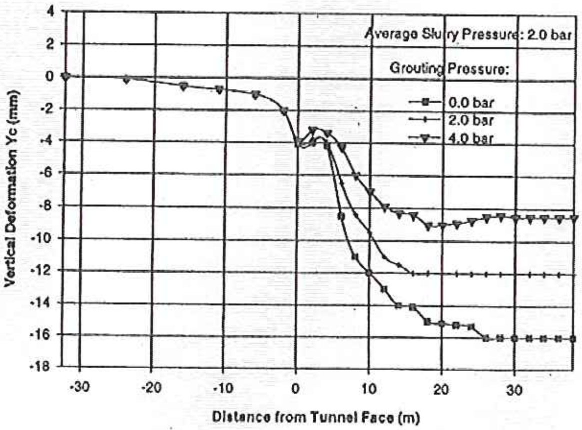

FIG 2b - Vertical deformation along crown for different values of grout pressure.

TUNNEL ALIGNMENT

Figure 1 shows a plan of the tunnel horizontal alignment under FAC land including airside with two underground railway stations, one at the International Terminal and the other at the

Domestic Terminal indicted. On to the approaches to both stations there is approximately 15 m of ground cover above the tunnel crown. Under the main north/south runway the vertical alignment of the tunnel left approximately 22 m of ground cover above the tunnel crown. The TBJV raised the tunnel alignment under the runway by approximately 3 m as a result of tunnelling experience gained prior to tunnelling on airside. The reason for this was to minimise the volume of sandstone rock intersected by the TBM. This would reduce the likelihood of an intervention under the runway into the head of the TBM to change disc cutters. The disc cutters have to be periodically changed as a result of excessive wear in the relatively abrasive Sydney Sandstone.

RISK AND HAZARD ANALYSIS

During an intervention on the TBM under the car park of the International Terminal a 'breakthrough' to the surface occurred, that is, soil slumped into the void created for the intervention which resulted in surface subsidence. The subsidence could be observed on the surface as a 500 mm deep slump approximately 1 m in diameter. The TBM was advanced through the disturbed area and the initial filling of the void was made by grout injected through the tail shield of the TBM. Later, three boreholes were drilled from the surface and cement grout injected from the surface to fill any remaining voids. The surface grouting did not take place initially so that the TBM could be moved from the area. One scenario that the TBJV wanted to avoid was permanently grouting the TBM into the ground! This incident resulted in the TBJV revising their procedures for interventions and in carrying out further risk/hazard analyses. Table 1 summaries some of the issues raised by these risk/hazard analyses. This event took place prior to the TBM advancing under airside of the airport (including the north apron and taxiways and the north/south runway). This event naturally raised the concern of all the various stakeholders, but particularly the FAC.

TUNNELLING UNDER THE INTERNATIONAL TERMINAL NORTH APRON

As mentioned above, during one intervention on landside, a surface slump occurred that if repeated on airside would be a major problem. The north apron of the International Terminal is used by Boeing 747, 767 and similar sized aircraft. The tunnel alignment is shown in Figure 3 passing under the paths used by these aircraft as they move into and reverse out from the terminal building and associated passenger Air Bridge. The shaded areas shown on Figure 3 are the aircraft wheel tracks. Another similar diagram not shown are the aircraft wing tip tracks. These tracked areas are important for two reasons. Firstly, the TBM could not under any circumstances stop for an intervention under the aircraft load tracks without disrupting airport operations. The risk of a breakthrough to the surface was just too high. If the TBM stopped for an intervention under an aircraft wheel load track the TBJV would have to have informed the FAC and aircraft could not use that particular passenger terminal bridge until after the TBM intervention. Aircraft would have to be diverted to another passenger Air Bridge at the terminal or passengers bused from the aircraft, if it could only be parked on a concrete hard stand area.

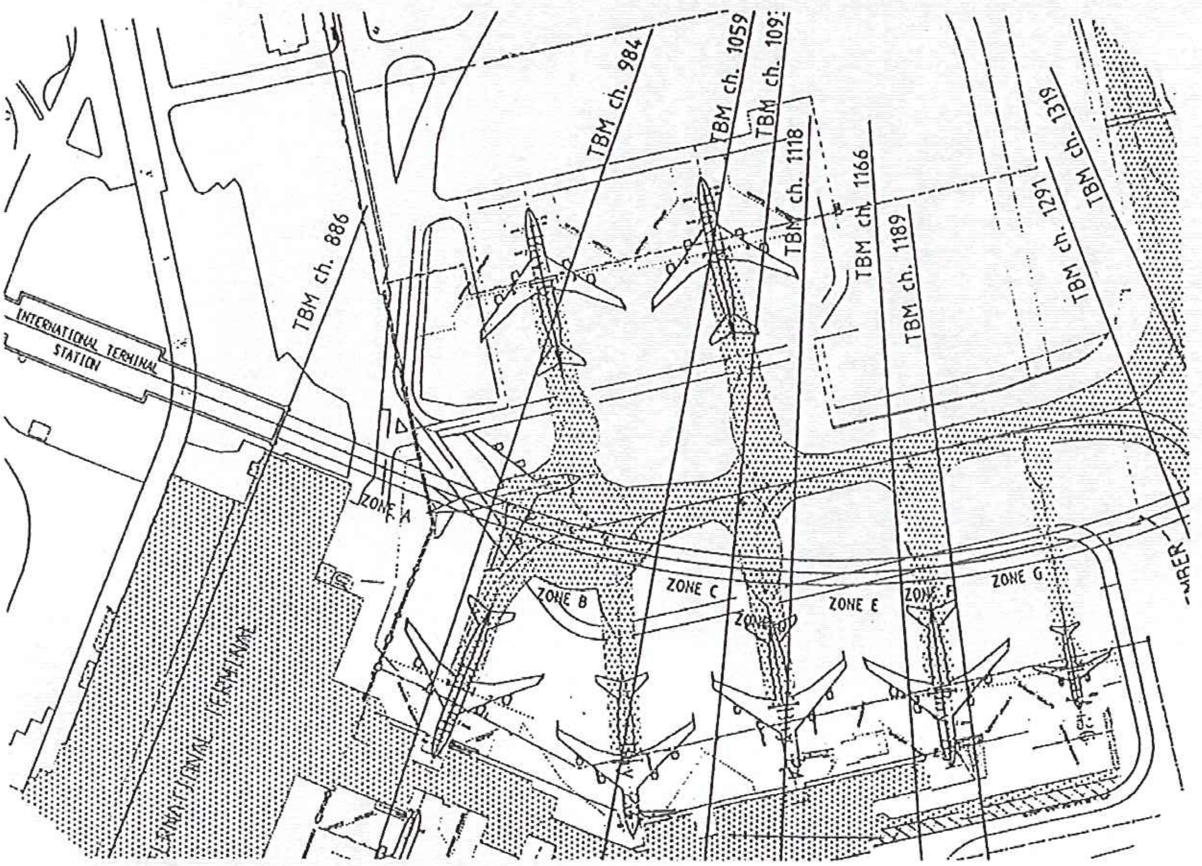

FIG 3 - Tunnel alignment under the north apron with aircraft wheel tracks shown.

TABLE 1
FAC land and north apron risk/hazard analysis.

Event	Probability			Consequences of disruption			Comments
	Low	Med	High	Low	Med	High	
1. Small void at cutterhead < 4 m^3			◆	◆			
2. Large void at cutterhead > 4 m^3 during intervention	◆					◆	
3. Segment seal failure (slurry flow in)	◆				◆		
4. Failure of tail shield brushes	◆				◆		
5. Having machine stopped							
1 day			◆	◆			
3 days		◆		◆			
7 days	◆				◆		
1 month	◆				◆		Major mechanical breakdown.
3 months	◆					◆	
6. Failure of slurry system pumps							
during intervention	◆					◆	No slurry pipe change and no maintenance on P1.1.
during excavation			◆	◆			Check mud quality continuously to reduce risk.
7. Failure of air confining pressure							
during intervention	◆					◆	Probability is very low because there are three compressors including one diesel to supply air.
during excavation	◆					◆	
8. Slurry treatment plant breakdown			◆	◆			Continuous checking of mud quality.
9. Power supply failure			◆	◆			Main supply is on the 705 feeder. Back up 702 feeder immediately available and emergency generator to keep pumps operational. Need to monitor mud quality.
10. Mud quality							
during intervention	◆					◆	No intervention unless mud quality OK.
during excavation	◆				◆		Due to tunnelling in clay.
11. Grout system failure	◆			◆			Two pumps, four lines, eight injection points, two in storage (ie five rings). No excavation if there is no grout.
12. Tree on route	◆			◆			It is highly likely that we have already come across a tree.
13. Main bearing failure	◆					◆	Continuous monitoring of forces/pressures and analysis of hydraulic fluid.
14. Failure of sealing of articulation	◆					◆	Two seals plus injection of mastic grease and polyurethane foam possible if there is a problem.
15. Unplanned intervention							Monitor/assess data acquisition and grout volumes continuously and especially. prior to evacuation of cutter head to determine if OK to do so.
without void			◆	◆			
with void 4 m^3	◆					◆	

The wing tip tracks are areas were drilling rigs, if required for surface grouting to fill a void, would also disrupt aircraft movements. For the above reasons prior to tunnelling under the north apron the locations of intervention points, were predetermined. Firstly, to minimise the consequences of a major surface slump and secondly to minimise (if possible) the disruption caused by equipment used to reinstate the north apron, eg drilling and grouting equipment.

A method that could have avoided risk altogether would have been a different horizontal alignment for the tunnel. However, the tunnel alignment was driven by the positioning of underground railway station between the current and future buildings at the International Terminal.

SETTLEMENT CRITERIA UNDER THE MAIN RUNWAY

FAC criteria

The full text of the FAC settlement criteria are given in the FAC Development Agreement Exhibits Volume 3, and are summarised below.

Settlement of main runway

Maximum differential settlement permitted along lines parallel to the main runway is 20 mm over 30 m in the form of a gradual change without any stepping *(which could be expressed as a slope of 1/1500).*

And from 'Rules and Practices for Aerodromes'

- the change in slope between two contiguous sections of runway is not to exceed 1.5 per cent *(which could be expressed as a slope of 1/70).*
- the transition from one slope to the next is to be a vertical curve, with a rate of change not exceeding 0.1 per cent per 30 m *(that is, a minimum radius of curvature of 30 000 m).*

Our calculations demonstrated that the second of the two dot point criteria given above is the most critical and was adopted as a basis to developing the criteria used and presented in Figure 4.

The slope and the settlement criteria adopted in Figure 4 are trigger points at which time a temporary Precision Approach Path Indicator (PAPI) installed by the FAC on the main runway would be required to be switched on. The temporary PAPI allows a shorter runway length to remain operational while maintenance is carried out to the runway surface.

In the process of the developing the settlement criteria a number of different approaches were assessed. It was decided that a quantitative analysis was required and for this reason polynomial curve fitting was used to 'iron out' the natural bumps in the existing runway surface. An example of the curve fitting approach is demonstrated in Figure 5. The radius of the polynomial curve fit was used for comparison with the FAC runway criteria. Figure 5 is an example of a polynomial curve fit and the summation of the adopted settlement criteria given in Figure 4 to the existing surface profile along the runway centreline.

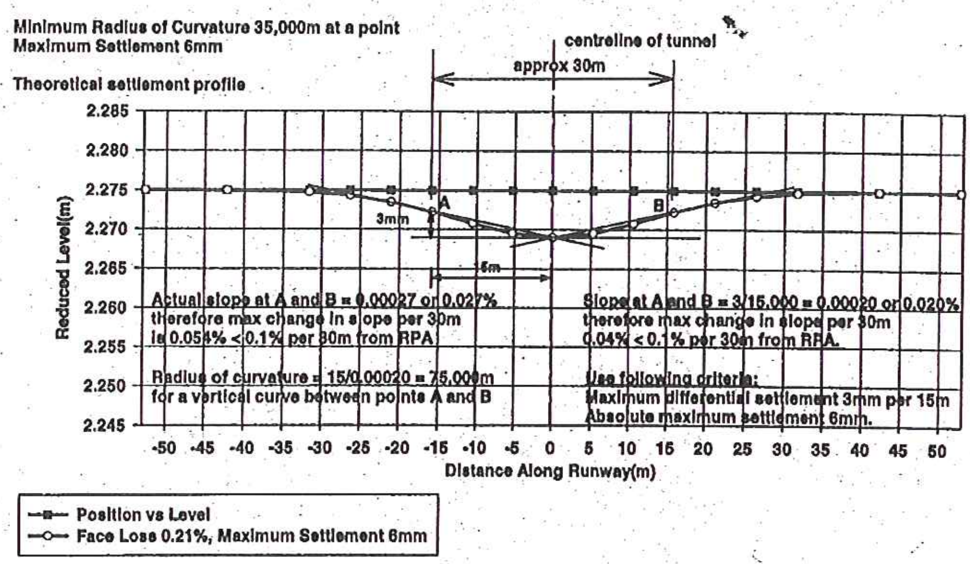

FIG 4 - Settlement criteria to comply with the rules and practises for aerodromes (RPA).

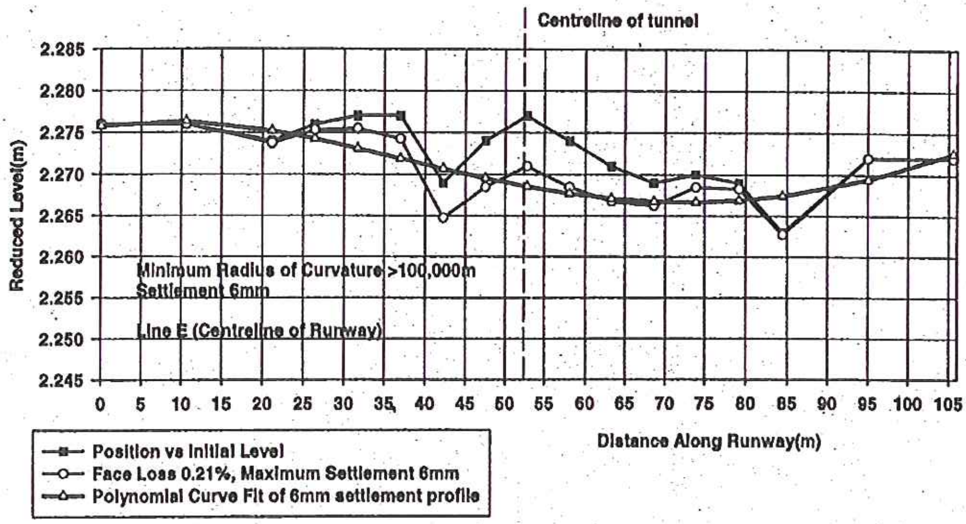

FIG 5 - Line E - polynomial curve fit to summation of settlement criteria curve and initial surface profile.

SETTLEMENT PREDICTIONS

The approach taken by Bouygues to predict settlement was to use a 2D finite element model. Our approach was to use an empirical method using the following equation which describes a normal distribution curve.

$$Y = Y_{max} \exp(-x^2/2i^2) \quad (1)$$

where Y is the settlement at a distance x from the tunnel centreline, Y_{max} is the maximum settlement (at x = 0), and i is the distance to the point of inflection of the normal probability curve.

The use of Equation 1 requires knowledge of two parameters, the maximum settlement Y_{max} and the point of maximum inflection, i.

The inflection point, i, on the settlement curve is also the point at which the maximum slope of the surface occurs and may indicate the most likely location of any damage to any surface structure or underground utility.

The width of the settlement trough is also a function of the ground volume loss due to tunnelling.

The volume of the settlement trough, V_s, under the probability curves is given by equation:

$$V_s = 2.5iY_{max} \quad (2)$$

and when given as a percentage represents the volume loss as a percentage of the cross-sectional area of the tunnel times a unit length of tunnel (ie volume of tunnel face).

The volume loss at the face of the tunnel is equal to the volume under the settlement surface curve. The tunnel face loss V_s for the estimates of settlement has been taken as 0.5 per cent (based on a limited literature search of published results from other slurry TBM and Earth Pressure Balanced (EPB) TBM projects).

O'Reilly and New (1996) have provided relationships for determining the point of inflection i of the settlement trough that are independent of the diameter D of the tunnel.

$$i = 0.43z_o + 1.1 \text{ for cohesive soils (ie clays)} \quad (3)$$

$$i = 0.28z_o - 0.1 \text{ for cohesionless soils (ie sands)} \quad (4)$$

where i and z_o are in metres.

Where z_o is the depth from the surface to the centre of the circular tunnel.

Equation 3 produces a shallower wider settlement trough compared Equation 4 which produces a deeper narrower settlement trough.

The above equations have been used previously to predict surface settlements in homogeneous soils. On the NSR project the geological profile under FAC land is sands or clays overlying clays. There is no point along the vertical tunnel alignment where the full face of the TBM intersects sands. For the purposes of the study where the crown of the tunnel intersects clays, Equation 3 was used. Where the crown of the tunnel intersects sand Equation 4 was used. This assumption will tend to over estimate settlements at the surface where the tunnel has a mixed face where sand overlies clay.

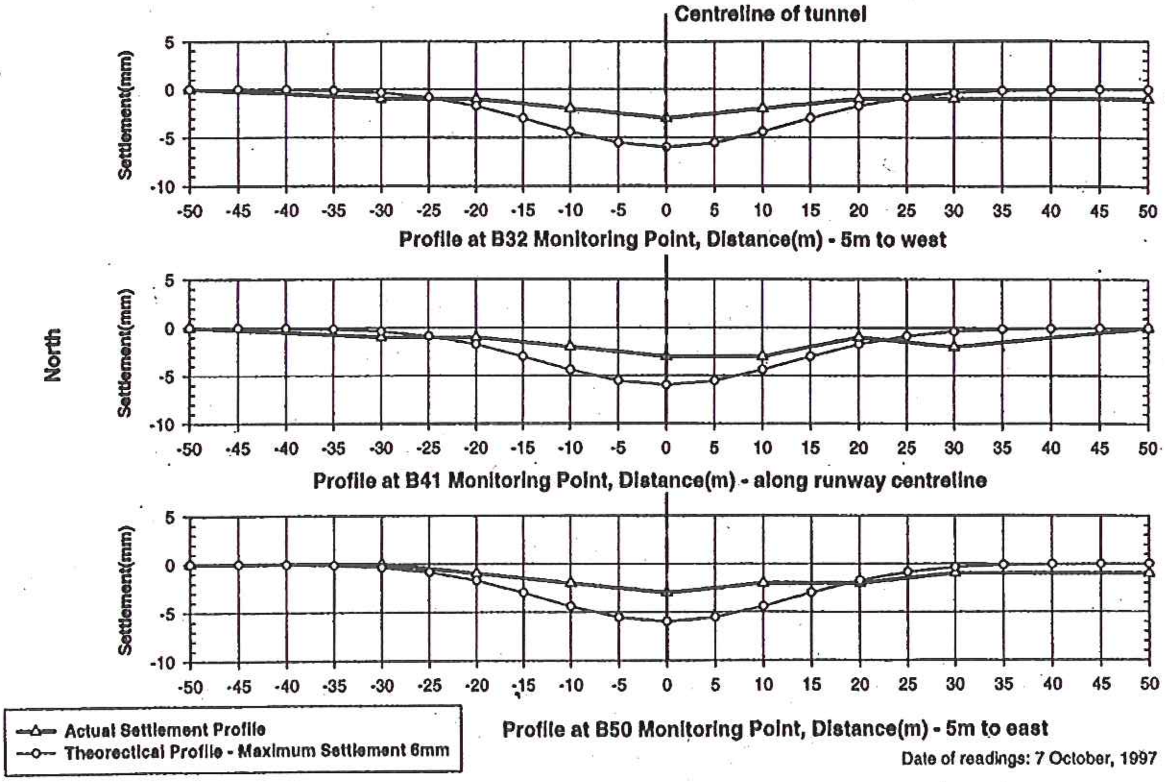

FIG 6 - Settlement profiles along runway.

The above four equations were used to determine the predicted surface settlement profiles across the tunnel and at 10 m intervals along the tunnel alignment under FAC land. The results of these analyses were presented as contour plans. The maximum settlement predicted under the runway using this approach was 12 mm with an assumed face loss of 0.5 per cent and by using Equation 3.

ACTUAL SETTLEMENTS UNDER THE MAIN RUNWAY

The TBJV used conventional precise levelling techniques to obtain spot levels at specific survey grid points along the tunnel alignment on the runway pavement surface. The frequency of the readings were once every 24 hours.

Using the initial survey level data a detailed contour plan of the runway was produced to assist in determining whether any prior defects existed in the runway surface. It was considered that the middle third of the paved runway surface was the most critical for aircraft operation and therefore only a 40 m strip of the full 60 m wide runway pavement width was contoured.

Settlement profiles

Selected settlement profile plots above the centreline of the tunnel and along the runway are given in Figure 6. These profile plots also show the settlement profile criteria adopted which is given in Figure 4.

It can be readily seen that the actual settlement profiles are similar in form to the criteria profile, although they are within the limits set by the criteria.

It must also be recognised that with such small settlement values the accuracy of the survey results will influence the final form of the profiles to some degree. It is estimated that the survey readings are accurate to within plus and minus 1 mm.

The profile plot readings also indicate a settlement trend to the right side of the graphs which may be associated with 'natural' movement of the ground and is not associated with the tunnelling works. Back calculating the volume loss at the face of the TBM from the settlement profiles indicates that the actual face loss is around 0.2 per cent, much less than the 0.5 per cent assumed in the initial predictions using the empirical approach.

Grout take volumes and grout pressure in tail of TBM

Grout is continuously pumped under pressure into the potential void between the concrete segments and the ground as the TBM is advancing. Plots of grout takes for each concrete segment lining ring erected in the tail of the TBM shield are given in Figure 7. In theory the volume of grout required to fill the 150 mm annulus behind each 1.8 m wide lining ring is approximately 9 m^3. Figure 8 also shows grout pressures for each lining ring under the runway. There are two grout take volume readings which appear to deviate from the norm. These are at ring numbers 751 and 764 where the grout takes are 6.8 m^3 and 14.6 m^3 respectively. There was no unusual confining pressures on the TBM nor other unexpected behaviour of the TBM at these locations. It can be noted from the Figure 8 that the grout pressure is relatively constant. The confinement or bubble pressure at the TBM face varied between 3.4 and 3.45 bar under the runway.

The evidence to-date is that these two grout take volumes do not indicate anything that would suggest that some type of void has formed above the tunnel. There is always, however, a remote possibility that an undetected void above the tunnel may travel with time to the surface.

Finally, Figure 8 shows the location of the TBM and its rate of progress under the runway. It was important that there were no interventions into the TBM chamber under the runway. This was achieved by having an extensive maintenance stop prior to the TBM crossing the runway.

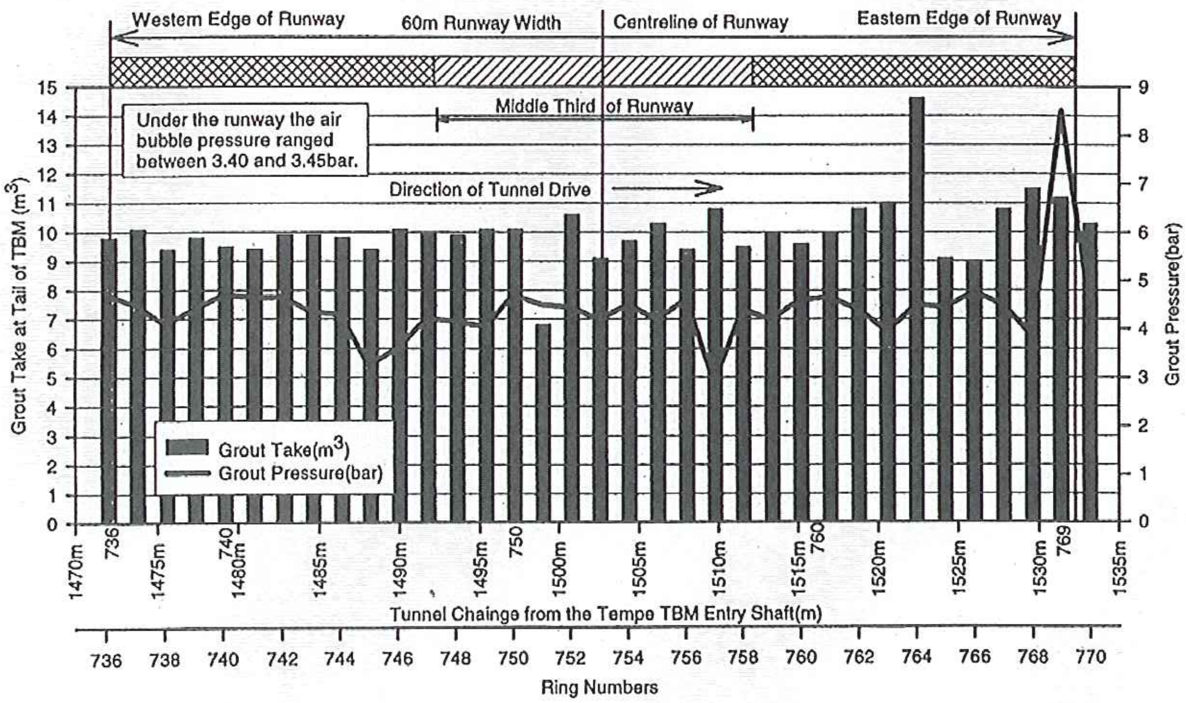

FIG 7 - Grout take volume (cum) and grout pressure (bar) at tail of TBM under the runway (lining ring nos 736 to 770).

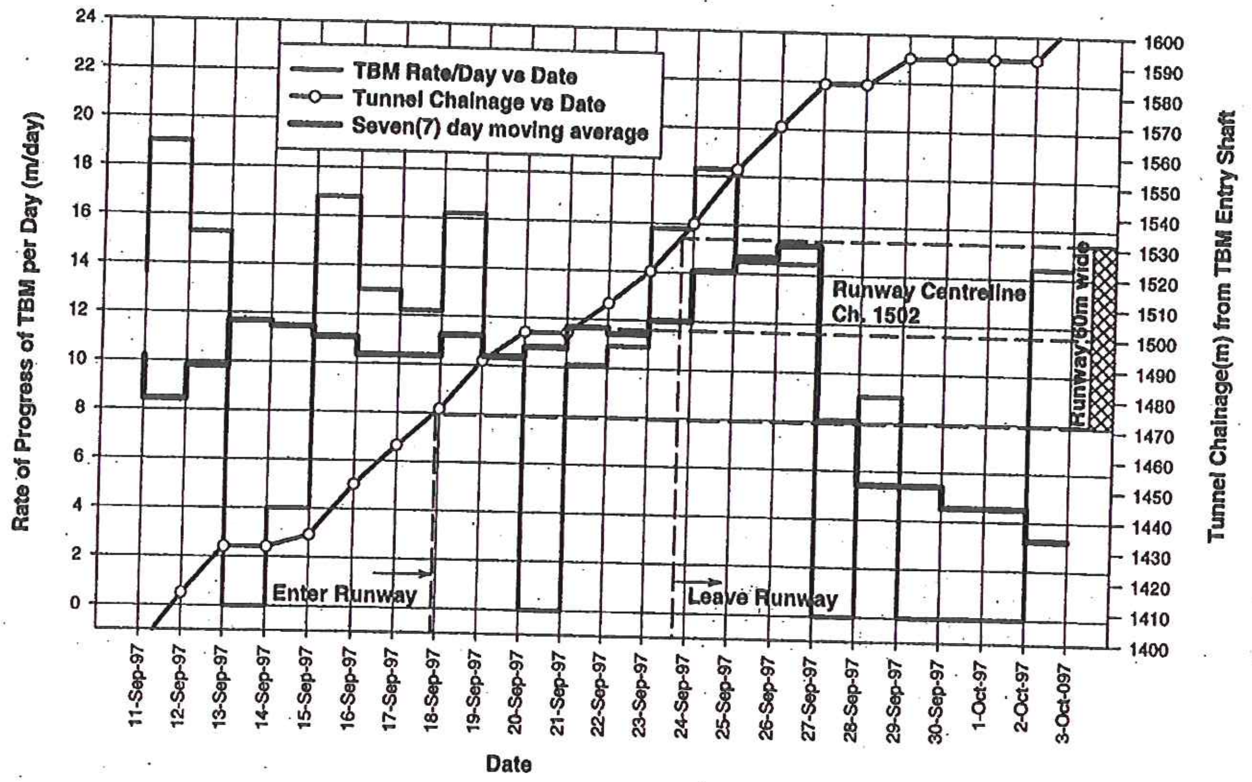

FIG 8 - Location and rate of progress of slurry TBM under the runway.

THE DOMESTIC TERMINAL ELEVATED ROADWAY

The FAC had let a contract to construct an elevated road at the airport Domestic Terminal building prior to the TBM advancing through this area. The elevated roadway required the construction of major caissons adjacent to the tunnel. The SRA/FAC development agreement included a sketch showing the clearance between any pile and the tunnel lining both before and after the tunnel was constructed. A modified similar sketch for the completed tunnel is reproduced in Figure 9. A greater clearance is required prior to the TBM passing through an area to allow for such factors as the need to maintain slurry face pressure and reduce the interaction between the TBM and other buried structures. What the development agreement did not envisage was that piling work would commence concurrently with the arrival of the TBM at a particular location. Neither the elevated roadway contractor, Transfield Constructions, or the NSR Project was prepared to tolerate construction delays due to each others project. After several meetings between all the parties involved, the elevated roadway contractor hastily reprogrammed the sequence of his piling works to comply with a new set of construction criteria issued by the NSR Project. The tunnel lining designers also specified that the piling works could not commence adjacent to the completed tunnel for at least eight to 12 weeks after the TBM had pasted a particular point. Their concern was that the grout annulus around the concrete segments would take at least 60 days to fully cure (the grout is not cement based and is slow curing to prevent grout pipe blockages on the TBM). The client (the RAC) argued that this was technically not a strong enough reason to delay the piling works and accepted the risk to the tunnel lining by allowing piling to commence after two weeks. The client believed the main construction risk was the potential for a pressure loss path to develop between the slurry face of the TBM and an open caisson hole (although all caissons were excavated under bentonite). A pressure loss could occur either in front of or behind the TBM. Piling works were allowed commence within two weeks after the TBM had pasted a particular point or after TBM breakthrough at the Domestic Station. The client argued strongly that the grout strength had only to be the same or more than the surrounding soil to allow piling works to take place if the tunnel lining was the only factor to consider. The pressure loss path is a separate issue as discussed above.

CONCLUSIONS

Sydney Airport has been successfully traversed by a 11 m diameter TBM without damaging or causing any major disruption to airport facilities or operations. The TBM slurry technology has proven to be the right choice by the TBJV. The risks associated with interventions on the TBM were assessed and procedures put in place to manage the identified risks. The empirical approach to predicting settlements under the runway are still applicable even with the latest tunnelling technology. Complex analyses can be avoided and the results easily understood by those not directly involved in the tunnelling works, which is important when there are a number of different stakeholders involved. It is unusual to be carrying out piling works in close proximity to soft ground tunnel construction. The initial criteria for piling adjacent to the tunnel was rapidly and successfully modified to satisfaction of the elevated roadway contractor and the NSR Project with no disruption to either project.

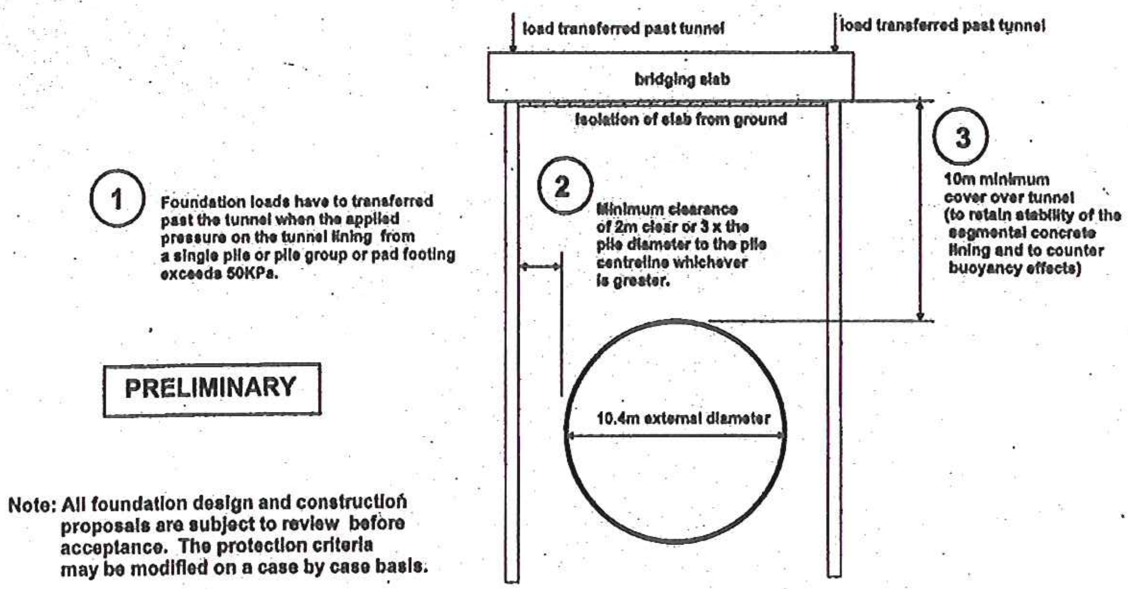

FIG 9 - Protection criteria for the existing soft ground railway tunnel under FAC land.

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ANA Hotel, Sydney, Excavation Adjacent to a Major Railway Tunnel

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SUMMARY

The excavation for building basements adjacent to existing tunnels in Sydney is becoming increasingly common. Although Sydney sandstone is an ideal medium in which to excavate for deep basements, their close proximity to existing railway tunnels requires additional design and construction supervision compared to other sites in similar material.

This paper presents a case history of a recently completed excavation on the ANA Hotel site. The excavation required the removal of approximately 55,000 cum of rock. The lift core of the 38 level building is located within a few metres of an existing twin track railway tunnel. Major building loads were transferred past the tunnel via caissons and the rock above and adjacent to the tunnel was reinforced by a combination of grouted dowels and tensioned ground anchors.

Finite element analyses were carried out to assist in the design of the protection measures adopted for the tunnel. The site was monitored by inclinometers, conventional surveying methods and by strain gauges placed over existing cracks in the tunnel lining. In-situ rock stress measurements were also carried out as part of the site investigations.

1.0 INTRODUCTION

1.1 Description of the Site

The ANA Hotel consists of a 38 level hotel development including four basement levels. The main core of the building is sited on the west side of a twin track State Rail Authority of NSW (SRA) tunnel which passes through the site between Wynyard and Circular Quay Railway Stations.

The site is bounded by the Bradfield Highway on the west, with Essex Street, Gloucester Street and the Cahill Expressway on the south, east and north respectively (refer to Figure 1).

The SRA tunnel is a twin track rail tunnel approximately 8.5m wide and 7m high. The unlined invert and walls of the tunnel are straight. The arched roof of the tunnel is unreinforced concrete and is reported to be approximately 600mm thick. Prior to commencing excavation on the site the adjacent excavation had already caused minor cracks to appear in the concrete lining. There was concern that the excavation for the ANA Hotel would cause additional cracking and therefore protection measures were adopted to limit the impact of the excavation on the tunnel.

This paper describes the analytical approach, the protection measures adopted, and the results of the field monitoring carried out during the excavation (previous case histories have been reported by Bennett and Nye, Reference 1).

The existing rock cover over the tunnel varies from 10.5m to 5.1m at the southern end. The excavated levels of rock above and adjacent to the tunnel are shown in Figure 1.

1.2 The Adjacent Excavation

East of the site a 30m deep excavation had been completed to R.L. -5m as part of another development (the D2 site). The pillar of rock separating the two sites in which the tunnel is located is quite narrow particularly at its northern end.

The D2 development involved the excavation of approximately 100,000 cum of sandstone rock. The western boundary is shown in plan in Figure 1. As for the ANA Hotel site, the vertical rock faces are unsupported in fresh sandstone.

1.3 Site Geology

The site is overlain with only a few metres of fill and highly weathered sandstone. The remainder of the excavation is in fresh sandstone. Very few vertical joints were intersected by the excavation. Details of the site geology are given in the geotechnical report for the site prepared by Peter Burgess & Associates (Reference 2).

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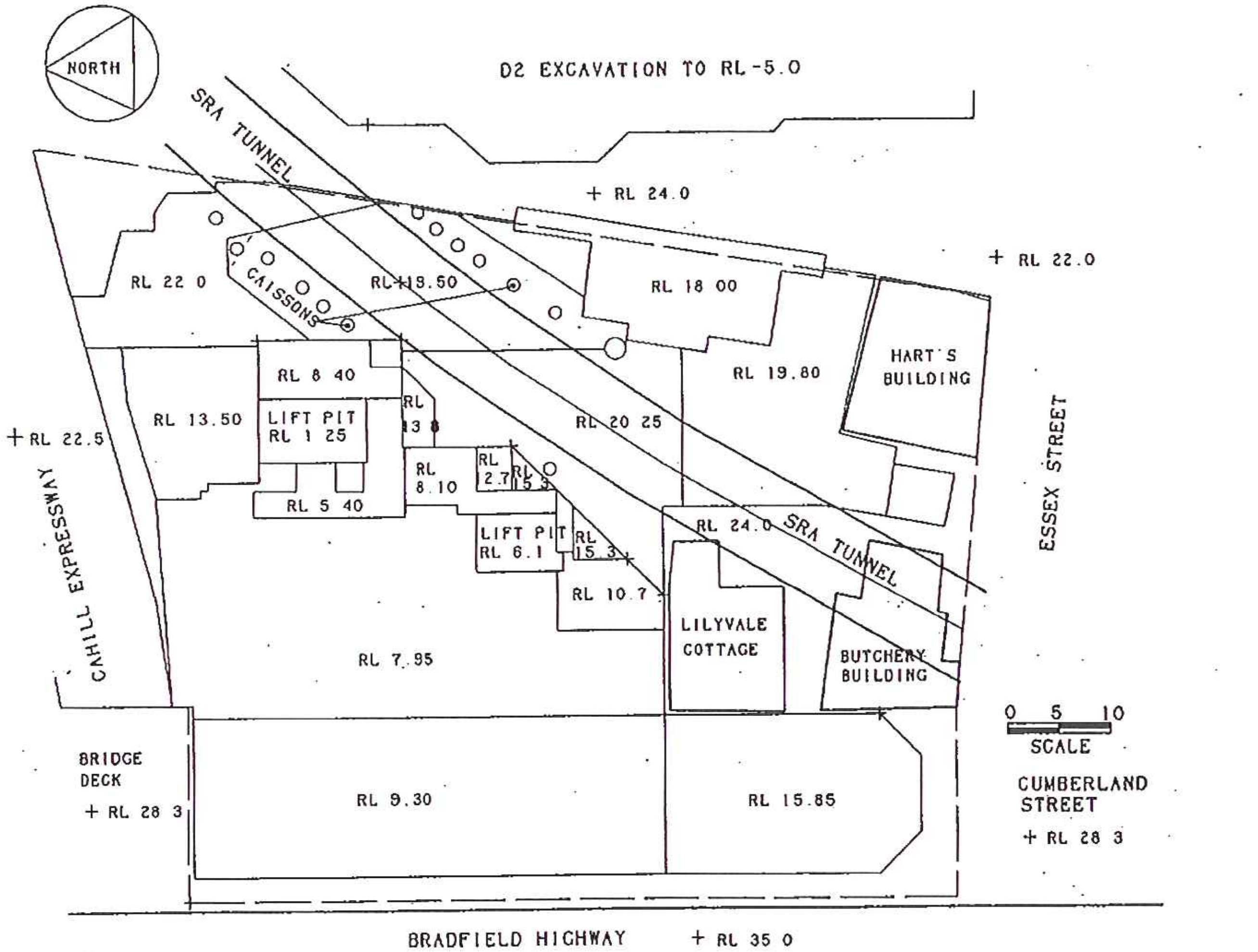

FIGURE 1 PLAN - BULK EXCAVATION ANA HOTEL SITE

2.0 EXCAVATION

2.1 Sequence of Excavation

The site is divided into zones with restrictions on the depth of excavation that could be carried out in each zone. For example, in the zone over the crown of the tunnel the rock could not be excavated below R.L. 21m (leaving 4.5m of rock cover) until the fourteen large diameter caissons had been drilled, the void between the tunnel lining and the rock fully grouted and vertical dowels (placed on a 2 X 2m grid) installed and grouted.

In a 20m wide zone adjacent to the tunnel excavation could not advance below R.L.18 until horizontal ground anchors had been installed and tensioned.

Section 5 and Figures 4, 5 and 6 provide details of the protection measures adopted for the tunnel(i.e. permanent structure load limits, structural isolation, grouting, inclined and vertical dowels and horizontal ground anchors).

2.2 Excavation Methods

Most of the rock on the site was excavated using a D10 bulldozer (weight 87 tonnes). The dozer was used to excavate the rock over the tunnel within 4.5m of the tunnel crown. Below this level above the tunnel crown the contractor was restricted to using excavation plant of not greater than 34 tonnes weight. This restricted the dozer size to a D8 or equivalent. However in the 4.5 to 3m cover zone above the tunnel crown a very hard unit of sandstone had to be excavated with rock breakers. The rate of excavation on the site is shown in Figure 2.

Fourteen caissons varying in diameter from 1.2m to 2m and up to 18m deep were excavated within 1.5m of the side wall of the tunnel. The drilling equipment used to bore the caissons weighted 115 tonne and was only allowed to pass over the tunnel if there was 4.5m or more rock cover.

The maximum velocity of vibration allowed by the SRA on the tunnel lining was 6mm/sec (frequency range to 10Hz). During excavation vibration levels were continuously monitored on the tunnel lining from within the tunnel. If the vibration limit was exceeded the contractor was informed immediately and excavation stopped. Steps were then taken to modify the excavation method (e.g. change angle of attack of rock breaker hammer).

3.0 IN-SITU STRESS MEASUREMENT

3.1 Description of the Field Tests

The tests were carried out by the CSIRO,

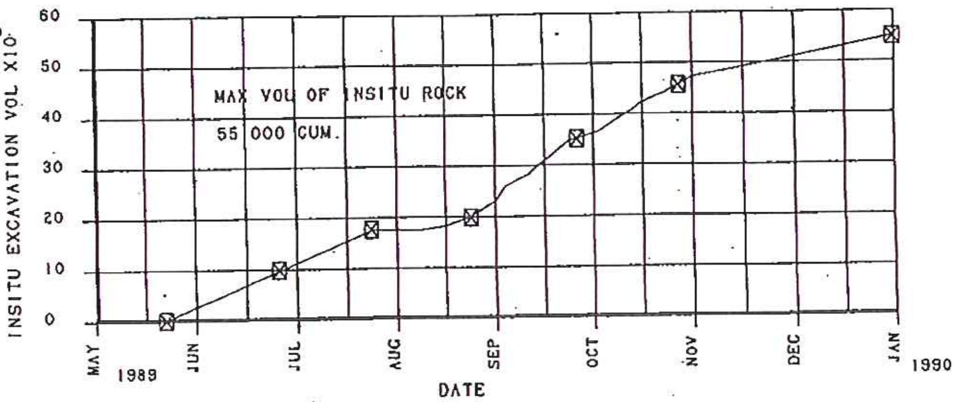

FIGURE 2 EXCAVATION RATE ON THE ANA HOTEL SITE

Division of Geomechanics, using the over coring technique with a CSIRO Hollow Inclusion (HI) Stress Measurement Cell that could measure the stress relief strains (Reference 3).

The tests were conducted between the 25th and 31st May, 1989. The associated laboratory tests were conducted on rock core samples recovered as part of the field work.

The tests involved drilling an inclined borehole from the adjacent D2 excavation at 17 degrees above the horizontal on a 270 degree bearing. The collar of the borehole was located at R.L. 9.72m. At four points along the borehole three dimensional in-situ stress measurements were taken (Figure 3).

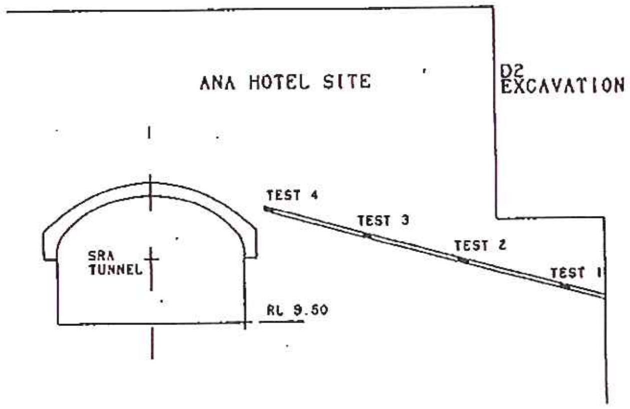

FIGURE 3 LOCATION OF IN-SITU STRESS MEASUREMENTS

3.2 Test Results

Table 1 is a summary of the measured principal stresses including their bearing and dip angle.

Table 2 provides a comparison between the calculated overburden stresses (taking the unit weight of sandstone as 25kN/cum) and the measured NorthSouth, EastWest and Vertical stresses measured in the field.

Discounting Test 1 and 4, for the reasons discussed below, it can be seen from the results given in Table 2 that the range of the ratio of horizontal stress to the measured vertical stress is between the values of 1.5 to 2.3 and confirmed the existence of a high horizontal stress field.

However, because of the complex geometry (the in-situ stresses were measured near the north west corner of the D2 site and in the rock pillar between it and the SRA tunnel), it is very unlikely that these are representative of the virgin stress field prior to the major excavations in the vicinity of the tests.

Test 1 vertical stress is an unexpected result because the test is located below an excavated ledge on the D2 site with only a few metres of rock cover.

Test 4 Vertical, NorthSouth, EastWest stresses would be strongly influenced by the close proximity of the stress concentrator at the intersection between the arch and the wall of the tunnel.

3.3 Interpretation of Results

The cause of the various stress levels and directions are very difficult to determine from these tests. One of the aims of the tests was to determine the 'background' or virgin stress levels on the site. It would be difficult to find any site in Sydney that has not been influenced by earlier construction activity. On this site this is particularly difficult because of previous construction involving these significant excavations:

i) SRA tunnel
ii) Cahill Expressway cutting
iii) D2 Excavation

It is likely that the test results are unique to the location of measurement.

Stress levels will vary for a given depth because of two significant factors.

i) the pillar of rock between the SRA tunnel and the D2 excavation varies in width.

ii) the proximity of the tests to the corner of the D2 excavation which is a stress concentrator (it was not possible to get access further away from this corner).

Test No.	P1 (MPa)	Brg1 (deg)	Dip1 (deg)	P2 (MPa)	Brg2 (deg)	Dip2 (deg)	P3 (MPa)	Brg3 (deg)	Dip3 (deg)
1	0.61	273	76	0.35	26	5	0.27	117	13
2	0.76	49	4	0.58	140	6	0.44	285	83
3	0.89	63	9	0.45	158	29	0.27	317	60
4	1.19	103	31	0.73	8	8	0.55	265	58

TABLE 1: PRINCIPAL STRESSES
P1=Principal Stresses, Brg1=Bearing, Dip1=Dip Angle

Test No.	Depth below existing surface (m)	Calculated Vertical Stress (MPa)	Measured Vertical Stress (MPa)	Measured NorthSouth Stress (MPa)	Measured EastWest Stress (MPa)
1	<3	0.08	0.59	0.34	0.31
2	12.1	0.31	0.44	0.65	0.68
3	10.6	0.27	0.33	0.51	0.77
4	9.1	0.23	0.72	0.75	1.00

TABLE 2: CALCULATED OVERBURDEN STRESS Vs MEASURED VERTICAL, AND HORIZONTAL NORTHSOUTH & EASTWEST STRESS.

It is significant however that despite the super-position effect of earlier excavations and the location of the tests that the stress levels of all readings are below 1 MPa (excluding Test 4 at a stress concentrator location close to the tunnel).

The only practical way in this situation to determine stress levels at various positions throughout the site would be to carry out a geometrically detailed 3D stress analysis. The purpose of the analysis would be back calculated boundary stresses. It is unlikely however that this method would be fully successful because of the very complex stress history of the site.

4.0 FINITE ELEMENT ANALYSES

4.1 Description of Model

A number of finite element analyses were carried out to determine the redistribution of stress in the rock mass and the tunnel lining. These analyses were two dimensional, plane strain, and linear elastic. The finite element grids were all at right angles to the line of the tunnel. The finite element grids also included the excavations of the ANA Hotel and the adjacent D2 excavation.

The values of the parameters used in the analyses were:

Concrete Modulus	20,000MPa
Poissons Ratio (concrete)	0.25
Rock Mass Modulus	2,500MPa
Poissons Ratio (rock)	0.3
Ratio Horiz/Vert In-situ Rock Stress	1

The finite element mesh consisted of 2500 quadrilateral elements. The tunnel lining (which is approximately 600mm thick) was modelled by 80 elements arranged in four rows.

The ratio of horiz/vert in-situ stress was taken as 1 and was considered a reasonable initial assumption for the analysis. The in-situ stress measurements were carried out during the early phases of the excavation contract and the results did not justify a re-analysis of the problem. It is important to note that as well as the in-situ stress ratio the relative stiffness of the ground to the concrete lining is a very important parameter in determining the stresses which will be attracted to the lining . A lower bound value for rock modulus was adopted for the initial analysis and had a higher in-situ stress ratio been subsequently used as a result of the field measurements than the in-situ modulus would have also been increased. The affect of increasing both these parameters would have tended to cancel one another out with respect to the stresses attracted to the tunnel lining which was the prime focus of concern.

4.2 Results of Analyses

4.2.1 D2 Excavation/ SRA Tunnel

As the tunnel lining had initially been cracked by the D2 excavation it was decided to model this excavation to determine the likely stress levels which had caused the cracks to develop. This was done using the same finite element model that would subsequently be used for the ANA Hotel site excavation.

Two cross sections were chosen. The first had a rock pillar width between the excavations of 4m and the second 37m. The first cross section indicated that the tunnel lining may have been subjected to a tensile stress of up to 2.32MPa and the second cross section 1.26MPa.

4.2.2 D2 and ANA Hotel and D2 Excavation/SRA Tunnel

At the 'typical' cross section chosen the rock pillar width between the tunnel on the and ANA Hotel side of the tunnel was 6m and on the D2 site side 20m. The combined tunnel lining maximum tensile stress determined from the analysis was 1.72MPa. The finite element analyses indicated that the tensioned horizontal ground anchors proposed would reduce the potential tensile stress in the lining by approximately 0.25MPa. This is a significant reduction when compared to the difference between the initial stress in the lining and the likely induced stress due to the excavation for the ANA Hotel without horizontal ground anchors.

4.2.3 Discussion

It is important to emphasize that the finite element analyses were two dimensional and therefore any section taken through the tunnel in the analysis models an infinitely long trench(i.e. plane strain analysis). In practice it was possible to leave a significant volume of rock at both ends of the tunnel on the site. This has created a three dimensional buttress effect and although not quantified would have had some influence in reducing horizontal ground movements.

5.0 TUNNEL PROTECTION MEASURES

The measures taken to protect the tunnel included:

1. Grouting the void between the rock and the lining in the crown of the tunnel.
2. Reinforcing the rock above and adjacent to the tunnel using a regular pattern of inclined and vertical fully grouted dowels.
3. Installing stressed horizontal ground anchors above the tunnel and prior to excavation below the levels of these anchors.
4. Excavation sequencing to limit stresses on the tunnel.
5. Limiting as far as practical the amount of excavation of rock in the vicinity of the tunnel.
6. Setting vibration limits for construction equipment.
7. Limiting the weight of construction equipment crossing over the tunnel under various rock cover conditions.
8. Bridging the tunnel and transferring major vertical building loads via caissons/piers past the tunnel.

Figure 4 shows the SRA load limits on the tunnel for the permanent structure. While the main tower of the hotel straddles the tunnel the pad footings of a three storey annex building are founded directly onto the rock overlying the tunnel. The design adopted a foundation bearing pressure limit of 100KPa for this structure which is slightly less than the SRA criteria.

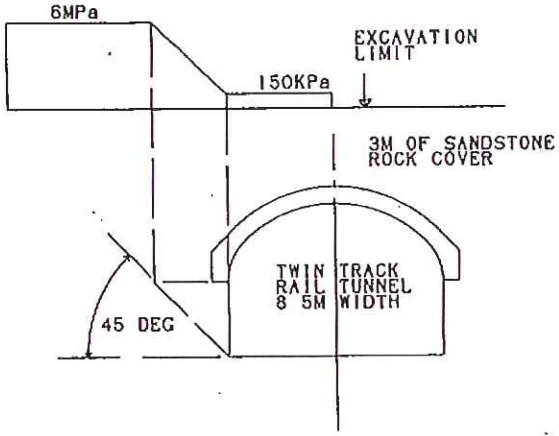

FIGURE 4 ALLOWABLE FOOTING LOADS OVER THE SRA TUNNEL

Figure 5 shows the concept of the 2.5m deep post tensioned transfer slab and caissons. During construction the transfer slab was poured onto a 200mm thick concrete bedding slab overlying 200mm of sand. After tensioning the sand is flushed from beneath the slab leaving a void that ensures complete isolation between the rock and the underside of this load bearing structure. The caissons are isolated from the tunnel by leaving a void of 50mm between two spiral ducts. Rubber pads ensured that the middle duct remained central during the pouring of the concrete and that in the permanent case train vibrations are not transferred to the structure. As a back up to surface drainage works drainage holes into the SRA tunnel above the rock sockets ensure that the caissons do not fill with water. The working loads on the 14 caissons vary from 7,000kN to 46,500kN.

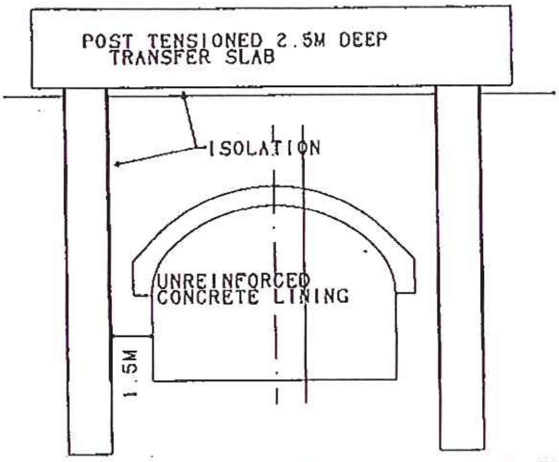

FIGURE 5 ISOLATION OF TUNNEL FROM TRANSFER SLAB & CAISSONS

The analyses indicated that stress relief due to excavation could not be fully compensated for in practice by near horizontal tensioned ground anchors. A reduction in the predicted stress levels was possible however. The main function of the vertical dowels and the horizontal ground anchors was to ensure that the ground remained monolithic (Figure 6).

All dowels consisted of galvanised 28mm deformed reinforcing bar placed in a 75mm diameter hole. The horizontal ground anchors consist of four 15.7mm diameter strands in a fully grouted 2mm thick polyethylene sheath having an ultimate capacity of 1000kN and working load of 400KN. The ground anchors were spaced at approximately 2m centres so that over the crown of the tunnel the confining pressure due to these anchors was approximately 70KPa.

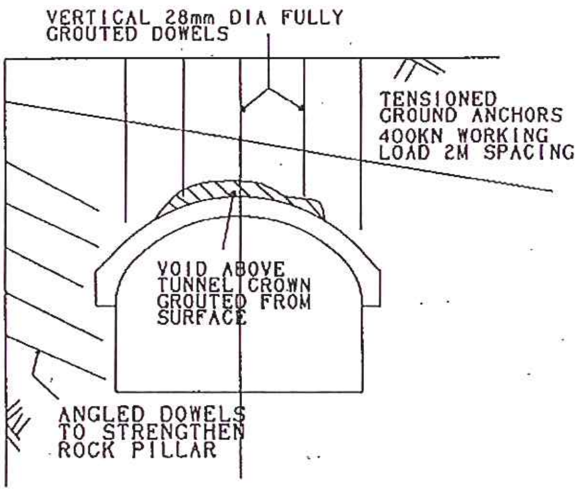

FIGURE 6 ROCK REINFORCEMENT ADJACENT TO TUNNEL

The anchor heads of these ground anchors were located at approximately R.L. 18.5m. The excavation specification, as mentioned in Section 2.0, required that all ground anchors over the SRA tunnel had to be installed and tensioned before the excavation could advance below R.L.18m within 20m of side of the tunnel.

Grouting of the void above the tunnel concrete arch, which were thought to be at least 500mm, was carried out from the surface using the boreholes drilled for the vertical dowels. The main purpose of grouting the void was to ensure that the rock mass and concrete lining acted together to support the imposed construction and permanent footing loads.

6.0 RESULTS OF FIELD MONITORING

6.1 The Tunnel Lining

As stated previously the adjacent D2 excavation had caused minor cracking in the tunnel lining in the section of tunnel under the ANA Hotel site. These existing cracks were either approximately diagonal to the centre line of the tunnel or parallel to the western boundary of the D2 excavation. Prior to excavation on the ANA Hotel site these cracks varied in width from 0.83mm to 1.38mm. The total length of cracks in the unreinforced concrete lining was 80m over a total length of 100m of tunnel.

As a consequence of this cracking the SRA installed vibrating wire strain gauges at five locations over these existing cracks to monitor any movement during the excavation for the ANA Hotel. The results of these measurements at selected dates are given in Table 3. At each location (L3,L5,L8,L14 and L16) one strain gauge was positioned perpendicular to the crack to measure the change in crack width. The second strain gauge at each location was positioned at an angle of 45 degrees to the crack to allow the calculation of lateral displacement or shear using the results of both strain gauge readings.

The bulk excavation on the ANA Hotel site commenced on the 19th May 1989. Prior to commencement of excavation there was still some measurable ground movement occurring due to the adjacent D2 excavation (refer to Table 3, and compare the strain gauge readings of the 1st March and 19th May).

By the 14th August the bulk excavation had advanced to R.L. 21m over the majority of the site. Thus approximately 5m of rock had been removed over the crown of the tunnel.

The holes for the large diameter caissons were drilled in late July and early August over a 2 week period.

During September the excavation had advanced to R.L. 18m and by the end of this month all vertical dowels, tunnel grouting and tensioned horizontal ground anchors had been installed or completed (refer also to Figure 2, Excavation Rate on the ANA Hotel Site).

Excavation around the tunnel was completed in November. This allowed the builder to have access to the site during this month. The remainder of the bulk excavation on the western side of the site under Cumberland Street was completed in late December 1989.

		1st March 1989	19th May 1989	14th Aug 1989	1st Sept 1989	30th Sept 1989	1st Jan 1990
Location L3	Width (mm)	0.78	0.84	1.12	1.12	1.12	1.09
	Shear (mm)	0	-0.05	-0.10	-0.11	-0.11	-0.15
Location L5	Width (mm)	0.73	0.83	1.25	1.38	1.38	1.30
	Shear (mm)	0	-0.04	-0.14	-0.14	-0.14	-0.10
Location L8	Width (mm)	1.30	1.38	1.70	1.70	1.58	1.2
	Shear (mm)	0	-0.05	-0.05	-0.05	-0.05	0
Location L14*	Width (mm)	0.02	0.03	0.30	0.30	0.30	0.30
	Shear (mm)	0	0	0.05	0.05	0.05	0.05
Location L16**	Width (mm)	1.10	1.22	1.60	1.59	1.59	1.36
	Shear (mm)	0	-0.02	-0.05	-0.05	-0.05	-0.11

TABLE 3: VIBRATING WIRE STRAIN GAUGES MEASUREMENTS OF CRACK WIDTHS AND SHEAR ALONG CRACKS IN THE CONCRETE ARCH OF THE SRA TUNNEL.

* The crack in the concrete lining at L14 is circumferential to the axis of the tunnel.
** L16 is located in the crown of the tunnel within the adjacent D2 site.

It is difficult to quantify the exact contribution of the protection measures adopted for the tunnel. However it is clear from the results given in Table 3 that these measures contributed to the closing of the existing cracks and, from inspections inside the tunnel, also prevented the development of new cracks.

6.2 The Ground Anchors

A total of sixteen ground anchors were installed horizontally (at a 5 degree dip) across the crown of the tunnel. Four of these anchors consisted of untensioned dowels. The tensioned anchors consisted of 4 strand ground anchors as described in Section 5.0. The untensioned dowels were used at locations adjacent to the holes bored for the caissons.

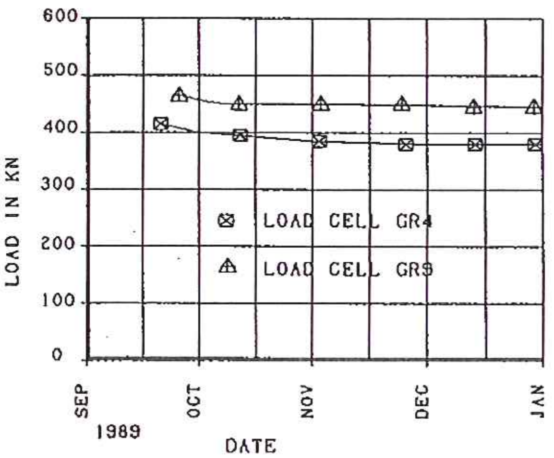

FIGURE 7 LOAD CELL READINGS ON GR4 & GR9

Two of the tensioned ground anchors, GR4 and GR9, were monitored by load cells. The ground anchor load records are shown in Figure 7.

It was thought that the ground anchor loads may increase as the excavation advanced. However the load cell results show that the ground anchor loads decreased slightly and then stabilised.

6.3 Displacement Monitoring

6.3.1 Surface Monitoring

Surface displacement monitoring points were placed around the perimeter of the site to measure horizontal and vertical displacements at the existing surface. The maximum horizontal displacement recorded was along the north wall of Lilyvale Cottage. The lateral movement of this building was approximately 7mm northwards and was the maximum recorded lateral movement on the site.

6.3.2 Tunnel Monitoring

Displacement monitoring stations were located at 20m intervals along the tunnel under the ANA Hotel site. Five monitoring points around the inside perimeter of the tunnel, to measure vertical and lateral displacements, were installed including one in the crown of the tunnel.

The maximum horizontal displacement was 5mm to the west and the maximum vertical displacement was a rise of 3mm although some points recorded settlements up to 2mm. The horizontal displacement readings are probably accurate to + or - 1.5mm and the vertical + or - 0.2mm on the walls and + or - 1.5mm in the crown. It was not possible to use a precise levelling staff in the crown of the tunnel because of the live overhead power lines. All survey work in the tunnel was carried out by Hard & Forester.

The accuracy of the readings could be affected by a number of factors. These include train vibrations and the confined working conditions in the tunnel making survey conditions less than ideal for precise survey monitoring.

6.3.3 Inclinometers

Five inclinometers were installed as part of the monitoring program, inclinometers were installed to measure lateral displacements across bedding planes. Inclinometers Nos. 1 and 2 monitored the west face of the D2 excavation and were installed to a depth of 35m. Inclinometer Nos. 3 and 4 monitored the south abutment of the Cumberland Street Bridge and the Bradfield Highway retaining wall.

Inclinometer 1 recorded a maximum incremental reading of 1.5mm at a depth of 16m and a maximum cumulative reading at the surface of 5mm towards the north. Inclinometer 2 recorded a maximum incremental reading of 0.5mm. Inclinometer No. 5 was installed 2m west of the tunnel with a drill hole collar at R.L 21m. Incremental movements of up to 0.2mm to the north were recorded at 13.5m and 16.5m below the collar level of this inclinometer.

It should be noted that the cumulative displacements measured at the collar of the inclinometers did not always agree with the lateral displacements indicated by the conventional surface survey monitoring. This was because it was difficult to obtain consistent sets of cumulative inclinometer readings (they varied by up to 100 percent between sets of readings). However the incremental readings from the inclinometers were consistent between different sets of readings.

7.0 CONCLUSIONS

This paper has described the analytical approach and some practical measures that can be adopted to assist in the protection of tunnels adjacent to large excavations.

The in-situ rock mass stress measurements demonstrate that their interpretation should be carried out with caution because of the probable complex history of ground stresses due to previous excavations.

The analyses showed that in-situ ground stresses cannot be fully compensated for in practice because it would be impractical to install the large number of ground anchors required. However the rock surrounding the tunnel can be assisted to behave in a monolithic manner (and thus keep the lining intact) using a combination of protection measures. These protection measures include pre-grouting the tunnel lining, vertical dowels over the crown of the tunnel to intersect horizontal bedding planes, inclined dowels adjacent to the tunnel wall and tensioned ground anchors over the crown of the tunnel.

The monitoring results, particularly the strain gauges monitoring the existing cracks in the tunnel lining, demonstrate that the objectives of the protection measures were achieved.

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